Essays on Inequality, Education, Trade and Endogenous Growth

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Abstract

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Inequality grew substantially not only in many developed countries during the 1980s and 1990s, but also in most developing countries. Across developing and emerging economies, the growth in inequality was more severe in Latin America and Africa compared with many East Asian countries. The diverse patterns of income inequality motivate my research, which reveals the important forces underlying the dynamics of inequality. In a general equilibrium, endogenous growth model, I show trade liberalization for a developing country with a low (high) quality of education induces a growth (reduction) of within country inequality during the dynamic transition. Moreover, trade liberalization leads to significantly stronger convergence in terms of per capita output when the quality of education is high in the developing country. Using large set of developed and developing countries, I then provide empirical evidence that technological progress increases the growth of inequality more in countries with a low quality of education. Taken together, this research shows the interaction between technological change and educational quality emerges as a principal determinant of the growth of inequality.

1. Within and Across Country Inequality in a Model of Trade and Endogenous Growth

1.1 Introduction

The distribution of income across individuals and across countries has long been an important issue in economics. This paper links income inequality both within and across countries, and presents a mechanism that can explain the varied dynamics of inequality among countries and regions. Within most developed and developing countries, the growth of inequality accelerated substantially during the 1980s and 1990s. Focusing on developing and emerging economies, the growth in inequality was more severe in Latin America and Africa compared to many East Asian countries.[1] Inequality across countries have also varied. Per capita GDP in Latin America and Africa, on average, fell relative to the U.S., while East Asia largely converged.[2] In a general equilibrium model of North-South trade with endogenous innovation (conducted by the North) and imitation (conducted by the South), I account for the varied dynamics of within and across country inequality by focusing on the quality of education and its interaction with technological progress. In the model, a higher quality of education improves the ability of workers to adapt to new technologies. Trade liberalization alters the pace of technological progress which, if the quality of education is low (high), induces a growth (decline) of within country inequality and divergence (convergence) in terms of per capita income during the dynamic transition.

In his seminal contribution, Kuznets (1955) suggests within country inequality will rise in the early stages of development where investment in physical capital is the engine of growth, yet decline in latter stages as human capital becomes the primary growth mechanism. To address the continued growth of inequality within developed countries, the theoretical literature often identifies skill-biased technical change and globalization as sources of changing

[1] Uses inequality data from the University of Texas Inequality Project (available at http://utip.gov.utexas.edu/data.html). The empirical evidence will be addressed in more detail in the following section.

[2] Data on GDP per capita is taken from Penn World Tables (Heston et al., 2006).

inequality. Galor and Tsiddon (1997), Greenwood and Yorukoglu (1997), Caselli (1999), Lloyd-Ellis (1999), Aghion et al. (2002) and Aghion (2002) focus on technological revolutions that give rise to an increase in demand for skilled workers which puts upward pressure on their relative wage. Acemoglu (1998) argues a sharp (exogenous) increase in the supply of skilled workers raises the return to innovations targeted at skill-intensive sectors which leads to an increase in their relative wage. Galor and Moav (2000) introduce the idea that the rate of technological progress determines the relative demand, and reward, for skilled labor.

The globalization argument (see Wood, 1994) stems from the Stopler-Samuelson theorem where the reduction in impediments to trade with skill-scarce countries increases the relative demand for skilled workers in the skill-abundant countries, and therefore raises the skill premium. The theory also suggests trade liberalization decreases the relative demand and premium for skills in less developed countries, which is not consistent with empirical evidence. Dinopoulos and Segerstrom (1999, 2006), Sener (2001), Acemoglu (2003), Grieben (2005) and Zeira (2007) provide more unified models of technology and trade that avoid the pitfalls of the Stopler-Samuelson theorem. Ripoll (2005) develops a general equilibrium model of trade and finds that initial conditions, such as the skilled-unskilled labor ratio, are important to the dynamics of income inequality following trade liberalization. While these papers emphasize the relationship between technology, trade and inequality, this paper focuses on why the dynamics of inequality differ among developing countries and also considers the implications for inequality across countries.

In addition to addressing the dynamics of inequality within countries, this paper also seeks to capture inequality across countries. The economic growth literature primarily focuses on the convergence hypothesis. The hypothesis generally asserts that differences in per capita income between any pair of countries will be transitory as long as they possess identical technologies, preferences and population growth rates. Empirical papers have found evidence that after controlling for savings rates and population growth rates, countries with low initial levels of per capita output tend to grow faster than those with higher initial levels of per capita output. Quah (1996a, b) and Galor (1996), among others, offer a contrasting view in which locally stable convergence clubs emerge, where there is a wide range of long run per capita output levels.

To capture the varied patters of inequality within and across countries, I focus on the interaction of the quality of education and the pace of technological progress. Workers are differentiated on a continuum of innate ability and make a discrete choice at each point in time as to whether acquire education and become a skilled worker, or remain unskilled, based on their individual expected income. To become skilled, the worker forfeits a fraction of their labor endowment to acquire education. This cost of education is decreasing in their innate ability, or, education is "cheaper" for those with a higher ability.[3] The benefits of education are two-fold. First, skilled workers have a productivity advantage in production relative to unskilled workers which is increasing in the rate technological progress. This flows from Ferguson (1993) and Bartel and Sicherman (1999) who find that technological progress increases the return to education.

The second benefit to acquiring costly education is a reduction in the time workers spend adapting, or learning, new technologies. In this model, both skilled and unskilled workers spend a portion of their labor endowment, not in production, but in this learning process. Bartel and Sicherman (1998) show that an increase in the rate of technological progress increases the need to (re)train workers, especially low skill workers. This feature is captured in this model as the portion of time learning is increasing in the pace of technological progress. For skilled workers, this learning cost is reduced. This introduces the role of the quality of education. A higher quality of education reduces the time spent learning new technologies for those who have made the discrete decision to acquire education.

Faster rates of technological progress have competing effects on the overall, effective human capital supplied to production. First, an increase in the rate of technological progress increases the relative productivity of skilled workers inducing more workers to acquire education and become skilled. This effect increases overall human capital. Second, faster rates of

[3]This assumption is line with Griliches and Mason (1972) and Murnane, Willett and Levy (1995) who find individual earnings increase with ability. In this model, because the cost of education is decreasing in ability, higher ability workers devote more of labor endowment to income earning production.

technological progress increase the time needed to learn and adapt to the new technologies, reducing the effective labor supply to production which decreases overall human capital. A higher quality of education reduces the strength of this second effect, and thus increases the marginal impact of an increase of technological progress on overall human capital. The overall impact of faster rates of technological progress is determined by the quality of education which is a key feature of the model.

The model is solved numerically using reasonable parameter values. I focus on the income inequality both within and across countries following Southern trade liberalization.[4] I consider two specific cases referring the quality of education in the South. The first is when the South has a low quality of education and the second is when the South has a higher quality of education.

In the long run, Southern trade liberalization increases the rate of technological progress and economic growth under both cases by a similar magnitude. Long run inequality within countries unambiguously increases in both the North and South due to the increased pace of technological progress, while long run inequality across countries decreases. The per capita income of Southern workers increase relative to Northern workers, however total profits for Northern producers of intermediate goods increase relative to Southern producers of intermediate goods. The intuition is that Northern producers face lower costs of exporting intermediate goods to the South following trade liberalization. Overall, the quality of education in the South does not significantly change the long run, qualitative implications of Southern trade liberalization.

The transitional dynamics of inequality within and across counties depend significantly on the quality of education in the South. In the case in which the South has a low quality of education, the rate of technological progress jumps initially, continues to increase in the initial periods of the transition, before declining to an overall higher rate of technological progress in the long run steady state. In contrast, when the quality of education is relatively high in the South, after an initial jump, the rate of technological progress declines in the

[4]In this class of models, the South refers a developing or emerging economy, whereas the North represents a developed country. Northern trade liberalization and bilateral trade liberalization experiments are possible in the context of this model. In the present paper, I focus on Southern trade liberalization.

early portion of the transition before increasing to a higher long run equilibrium. The nonmonotonic transitional dynamics are directly due to the quality of education in the South. When the quality of education is low, the initial jump in the rate of technological progress following trade liberalization reduces overall human capital in the South (for the reasons discussed above), which limits their ability to imitate and further increases the incentives for Northern firms to innovate. The initial jump in the rate of technological progress increases overall human capital when the quality of education is high. This increases the ability to imitate in the South, reducing the incentives for Northern firms to innovate, and leads to the decline in the rate of technological progress in the early stages of the dynamic transition.

Inequality within countries follow the nonmonotonic transition of the rate of technological progress. Focusing on the initial periods following trade liberalization, within country inequality declines when the quality of education in the South is high, but increases when the quality of education is low. In addition, the per capita income of Southern workers converge to that in the North in both the transition and in the long run when their quality of education is high. Per capita income for Southern workers, conversely, diverges during the initial periods of the transition when the quality of education is low. The quality of education emerges as an important determinant of the varied dynamics of within and across country inequality observed in the data. Empirical evidence supports this claim. Using data compiled by Hanushek and Kimko (2000), which provides a measure for the quality of education based on math and science scores, I provide empirical evidence which shows a higher quality of education both directly reduces the growth of within country inequality and the marginal impact of technological diffusion on inequality, which is consistent with results of this model.[5] In addition, Hanushek and Kimko use their measure to show the quality of education is positively related to the economic growth in developing countries.

The remainder of the paper is organized as follows: Section 1.2 provides an overview the empirical motivation; Section 1.3 introduces the model; Section 1.4 details the steady-state and transitional dynamics; Section 1.5 discusses the implications of Southern trade liberalization on within and across country inequality; and Section 1.6 concludes.

[5]See the followin chapter.

1.2 Empirical Motivation

1.2.1 Within Country Income Inequality

The empirical literature on within-country income inequality is extensive. By most measures, inequality within the United States and other industrialized countries rose from the 1970s until 2000 (Wood, 1994; Machin, 1996; Autor et al., 2005). However, among developing countries there is no such clear pattern. Latin America, for example, experienced a growth in income inequality, while inequality within many East Asian countries declined. Hanson and Harrison (1999) show the skilled/unskilled wage gap grew in Mexico during the 1980s. Robbins (1996) and Wood (1997) find inequality also grew in Hong Kong, Argentina, Chile, Colombia, Costa Rica, Uruguay and Mexico, but fell in Korea, Taiwan, Singapore and Malaysia during the same period. Das (2002), similarly, finds rising income inequality in Mexico and Chile, and falling inequality within Philippines, Singapore and Taiwan. Duryea and Szekely (2000) and Behrman, Birdsall and Szekely (2000), on-the-other-hand, show inequality fell within Brazil, Mexico, Venezuela, Argentina and Bolivia, and was constant in Chile and Costa Rica during the 1980s and 1990s. Michaely et al. (1991) show a rise and then fall of inequality within Singapore and Sri Lanka. Zhu and Trefler (2001) find that out of 29 developing countries, inequality is rising in 16 countries and falling (or remaining constant) in 13 countries.

The empirical literature focusing on the dynamics of within country inequality is certainly mixed. To provide a more uniform consideration of within country inequality, Figure 1.1 shows the median of the log change of the Theil index for five country cohorts: advanced countries, Middle Eastern and North African countries, Latin American countries, Sub-Saharan African countries and Asian countries (UTIP-UNIDO, 2002). The data spans from 1960 until 1995 and is broken up into six ten-year periods. This measure, first introduced by Theil (1967), is a consistent measurement of inequality based on industrial wages in the manufacturing sector published annually by the United Nations Development Organization.[6]

[6]Another commonly used measure of inequality is the Gini coefficient (Deininger and Squire, 1996; 1998). However, this measures the concentration of income based on household surveys (See Deininger and Squire, 1996). Conceicao and Galbraith (2000) and others also find this measure to be incomplete in terms of

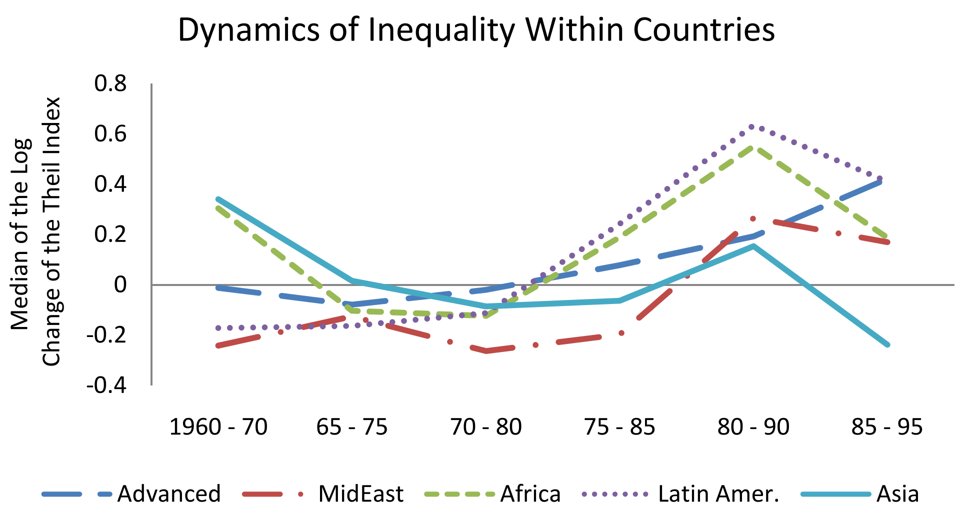

Figure 1.1: Median log change in the Theil index over ten year intervals for five country cohorts: Advanced economics, Middle East/North Africa, Africa, Latin America, and Asia. For each country the data were averaged around years given. For example, the Theil for 1980 is the average of 1978-1982 and the value for 1990 is the average of 1988-1992 for each country.

The median growth of inequality was negative or zero for each of the five groups of countries between 1965 and 1975, as well as from 1970 to 1980. However, the growth of inequality accelerated substantially during the 1980s for most groups of countries. The relative magnitude of the growth of inequality in the 1980s is also important. Inequality grew substantially more in Latin America and Africa relative to the other three cohorts, while the growth of inequality was lowest in the Asian countries for the periods 1980-1990 and 1985-1995.

1.2.2 Across Country Income Inequality

When addressing inequality across countries, one approach is to view countries as a unit of measure. Under this assumption, the empirical convergence literature established divergence in GDP per capita, most notably due to the poor economic performance of many Latin American and African countries. Specifically, the growth rates of poor countries have been lower than the growth rates of rich countries,[7] and the dispersion of income per capita across countries has increased over time.[8]

This finding of divergence, however, is not robust when considering the individual as the unit of measure. The convergence of more populous regions, including China and India, drives a decline in global inequality across all individuals. Overall, recent empirical evidence suggests that after peaking around 1979 global inequality is declining (See Sala-i-Martin, 2006).

Abstracting from the convergence debate, the focus of this paper is why certain countries diverged and others converged in terms of average GDP per capita relative to that in the United States. Figure 1.2 uses data from the Penn World Tables 6.3 (Heston et al., 2009) to show the GDP per capita relative to the U.S. GDP per capita for a subset of African, Latin American and East Asian countries from 1960 to 2002. Figure 1.2 shows East Asia, on average, converged substantially in terms of living standards, while both Latin America and Africa experienced divergence. Also, the convergence of East Asia and the divergence of

country coverage over time and largely inconsistent with other measures of inequality.

[7] β-divergence in Barro and Sala-i-Martin (1992) terms.

[8] σ-divergence in Barro and Sala-i-Martin (1992). See the “twin peaks” literature following Quah (1993).

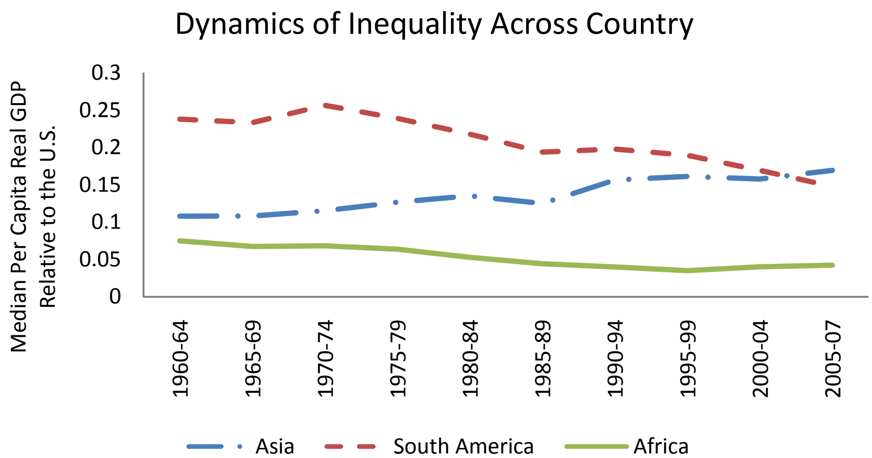

Figure 1.2: Median of the real GDP per capita relative to the U.S. for 3 country cohorts. For each country, the relative GDP per capita was averaged over 5 year intervals, then the median for each year group was calculated. The Asian sample included 14 countries; 11 countries were included in South America; and 37 countries in the African sample.

Latin America and Africa accelerated during the 1980s. This decade is known for widespread trade liberalization among developing countries, which suggests that opening to trade and new technologies that flow into the country may be an important source of the dynamics of income inequality.

1.2.3 Quality of Education

The quality of education varies widely across countries. Standard measures for educational quality, including adult literacy rates, teacher-pupil ratios, or expenditures per student, are typically insignificant in cross-country growth studies, and are notoriously poor measures for the quality of education in the labor force. A potential reason is that these measures to do not directly capture the cognitive ability of the labor force. Hanushek and Kimko (2000) address this issue and develop measures for the quality of the labor force derived from a number of international mathematics and science tests between the years 1965 through 1991. While test score data is available for only 38 countries, Hanushek and Kimko use consistent estimators to forecast labor force quality for a large number of countries based on country specific characteristics. In all, they produce quality measures for 90 countries across the development spectrum. Table A.1 in the appendix provides the quality indices derived in Hanushek and Kimko (2000).

The quality of the labor force is consistently higher in Asia relative to Latin America, and the measure performs well in cross-country growth regressions. Using the Hanushek and Kimko measure, the poorest quality of the labor force is 18.26 (Iran), while the highest is 72.13 (Singapore). The mean for the entire sample of countries is 51.28. Overall, this data supports the idea that the quality of education varies significantly and systematically across countries and regions.

1.3 The Model

The model features North-South trade with Schumpeterian endogenous growth through creative destruction in continuous time. The North represents a developed country, while the South represents a less developed country. Innovations increase the quality, or productivity, of intermediate goods used in final goods production. State-of-the-art quality levels are only discovered through research and development (R&D) efforts in the North, but once an innovation occurs, the South undertakes R&D to imitate the Northern frontier technology.

Human capital is an input for final goods production. As introduced by Galor and Moav (2000), the rate at which new state-of-the-art technologies enter the production process determines, in part, the level of effective human capital in the economy. The effective human capital in the economy is a weighted sum of skilled and unskilled workers whose productivity and effective supply to production are determined by the quality of the education and the rate of technological progress.

1.3.1 Final Goods Sector

The final goods production function includes a conventional quality ladder model, a la Grossman and Helpman (1991), Aghion and Howitt (1992), and Barro and Sala-i-Martin

(1997, 2004). In this setup technology is embedded within the productivity, or quality, of the intermediate goods used in producing a final good. Denote the productivity of a given intermediate good industry j to be q^{k_j}, where q is the incremental rise in productivity per innovation, and k is the number of innovations. Assume a continuum of intermediate goods, $j \in [0, 1]$.

Final goods production in each region $m \in [N\,(\text{North}), S\,(\text{South})]$ takes the Cobb-Douglas functional form,

$$Y_m = A_m \left(L_m H_m\right)^{1-\alpha} \int_0^1 \left(q^{k_{N_j}} x_{mk_j}\right)^{\alpha} dj \tag{1.3.1}$$

where α is the share of capital in production, A_m is the total factor productivity parameter in the final goods sector, x_{mk_j} is the physical quantity of intermediate good j with quality level k, and $q^{k_{N_j}} x_{mk_j}$ is the quality adjusted input for the intermediate good from industry j. The inclusion of N in $q^{k_{N_j}}$ indicates that in equilibrium only the highest quality of intermediate good will be used in final goods production, which by definition, is discovered only through Northern innovative activity. H_m represents the effective human capital of each country. Embedded within H are the contributions of both skilled and unskilled workers, whose supply and productivity are both endogenous and determined in equilibrium. L_m is the size of the population, normalized to $L_N = 1$ in the North. For simplicity, there is no population growth and workers are immobile across countries.

The inverse demand for an intermediate good x from industry j is

$$P_j = \alpha \tilde{P}_m \left(L_m H_m\right)^{1-\alpha} x_{mk_j}^{\alpha-1} q^{k_{N_j}\alpha} \tag{1.3.2}$$

where P_j is the price of the *intermediate* good from industry j, and $\tilde{P}_m$ is the price of the (nontradeable) *final* good. The price of the Northern final good, $\tilde{P}_N$, is the numeraire, $\tilde{P}_N \equiv 1$. Therefore, $\tilde{P}_S$ is defined as the relative price of the final good in the South. As later sections discuss, $\tilde{P}_S$ is endogenous, and adjusts in every period to balance trade.

1.3.2 Human Capital

Individuals choose between working as skilled or unskilled based on their expected income, thus the supply of each type of labor is endogenous. Workers are differentiated by their innate, cognitive ability which is reflected in their individual cost of education. A uniformly distributed continuum of individuals i in each region is indexed by ability a_{mi}. Each worker is endowed with one unit of labor at every point in time. To become skilled, the individual devotes a fraction of their labor endowment to the acquisition of education. The effective supply of labor to production for individual i as a skilled, h_{mi}, or unskilled, l_{mi} worker takes the form of:

$$h_{mi} = a_{mi} - \frac{1}{\delta_m} (1 - a_{mi}) p_I \tag{1.3.3}$$

or

$$l_{mi} = 1 - (1 - a_{mi}) p_I \tag{1.3.4}$$

efficiency units of labor to final goods production. The first term on the right hand side of equations (1.3.3) and (1.3.4) captures the labor endowment net costs of education. An unskilled worker supplies their full labor endowment of 1 to production, while a skilled worker supplies a_{mi} to production. The remaining $1 - a_{mi}$ is lost due to the cost of education. The second term on the right hand side is the time cost required for worker i to adapt to new technologies. This time cost is increasing in p_I which is the (endogenous) instantaneous probability of innovation, which captures the pace at which new technologies are entering the production process. Faster rates of innovation reduce the effective supply of labor to production. This learning cost is decreasing in ability (ie. higher ability workers learn and adapt to new technologies at a faster pace). Finally, $\delta_m > 1$ is the quality of education received by skilled workers who made the costly investment into acquiring education. A higher quality of education reduces the time that skilled workers need to learn new technologies.

I assume that in equilibrium $1 > p_I \geq 0$, and choose parameters such that this inequality holds in steady state and during each moment in the dynamic transition. The second part of this inequality ensures that the endogenous instantaneous probability of innovation is non-negative. The first part of the inequality ensures that the worker with the lowest ability will have a non-negative supply of production labor (after subtracting the time spent learning new technologies) as either a skilled or unskilled worker.

In the spirit of Galor and Moav (2000), the aggregate effective human capital H is given by a weighted sum of the endogenous aggregate effective labor supply of skilled and unskilled workers. The effective human capital takes the form of,

$$H_m = (1 + \delta_m p_I)\, h_m + l_m, \tag{1.3.5}$$

where $h_m = \int_{h_{mi}} h_{mi} da_{mi}$ and $l_m = \int_{l_{mi}} l_{mi} da_{mi}$ are the total effective supply of labor to production for skilled and unskilled workers.[9] A higher quality of education, δ_m, increases the relative productivity of skilled workers who made the costly investment into acquiring education. Finally, faster rates of technological progress also increase the relative productivity of skilled workers.

Using equations (1.3.1) and (1.3.5), the competitive wages for skilled (s) and unskilled (u) workers in country m are

$$w_m^s \equiv \omega_m (1 + \delta_m p_I) \text{ and } w_m^u \equiv \omega_m, \tag{1.3.6}$$

where $\omega_m \equiv (1 - \alpha)\, \frac{\tilde{P}_m Y_m}{H_m}$ is the marginal product of overall human capital. Income is the wage rate times the efficiency units of labor supplied. The individual with ability a_{mi} earns income I_{mi}^s working as a skilled worker, or I_{mi}^u if unskilled:

$$\begin{aligned} \text{Skilled} \quad &\Rightarrow \quad I_{mi}^s &= \quad& w_m^s h_{mi} = w_m^s \left(a_{mi} - \tfrac{1}{\delta_m} (1 - a_{mi})\, p_I \right) \\ \text{Unskilled} \quad &\Rightarrow \quad I_{mi}^u &= \quad& w_m^u l_{mi} = w_m^u \left(1 - (1 - a_{mi})\, p_I\right). \end{aligned} \tag{1.3.7}$$

At each point in time, worker i makes the discrete choice of whether to acquire education

[9]Introducing imperfect substitution between skilled and unskilled workers is possible, but the qualitative results would carry through and the analysis would be less transparent.

and work as skilled or remained unskilled by maximizing potential income as skilled, I^s_{mi}, or unskilled, I^u_{mi}. There is a single threshold level of ability, a^*_m, such that all workers with ability $1 > a_{mi} > a^*_m$ choose to acquire education and work as skilled, while all workers with ability $0 < a_{mi} < a^*_m$ remain unskilled. It is straightforward to show that $I^s_m (a_i = 0) < 0$, $I^u_m (a_i = 0) > I^s_m (a_i = 0)$ and $I^s_m (a_i = 1) > I^u_m (a_i = 1)$. Since income for skilled and unskilled workers are increasing in ability in a linear fashion, there is a single worker whose ability is such that $I^u_m (a_i = a^*) = I^s_m (a_i = a^*)$.

The threshold ability level of the worker indifferent from becoming skilled or remaining unskilled is given by a^*_m:

$$a^*_m = \frac{1 - p_I + (1 + \delta_m p_I) \frac{p_I}{\delta_m}}{1 - p_I + (1 + \delta_m p_I) \frac{p_I}{\delta_m} + \delta_m p_I}. \tag{1.3.8}$$

Any worker with ability $1 > a_{mi} > a^*_m$ will choose to become skilled, while the rest, $0 < a_{mi} < a^*_m$, choose to remain unskilled. a^* is interpreted as the fraction of workers of workers who choose to remain unskilled for a given quality of education and the rate of technological progress.

Figure 1.3 plots the skilled and unskilled incomes across individuals. The dark line shows the maximum potential income for each individual. Moreover, Figure 1.3 shows the impact of an increase in the rate of technological progress on the educational decisions in each country. For a given ability level, an increase in the rate of technological progress lowers the income of working as unskilled and increases the income of working as skilled. As a result, more workers will make the discrete choice to acquire education.

The threshold level of ability decreases in the quality of education which implies that an increase in the quality of education will increase the fraction of workers which choose to acquire education:

$$\frac{\partial a^*_m}{\partial \delta_m} = -\frac{p_I (1 - p_I) + \frac{p_I^2}{\delta_m} (2 + \delta_m p_I)}{\left(1 - p_I + (1 + \delta_m p_I) \frac{p_I}{\delta_m} + \delta_m p_I\right)^2} < 0. \tag{1.3.9}$$

An increase in the rate of technological progress also decreases the threshold level of

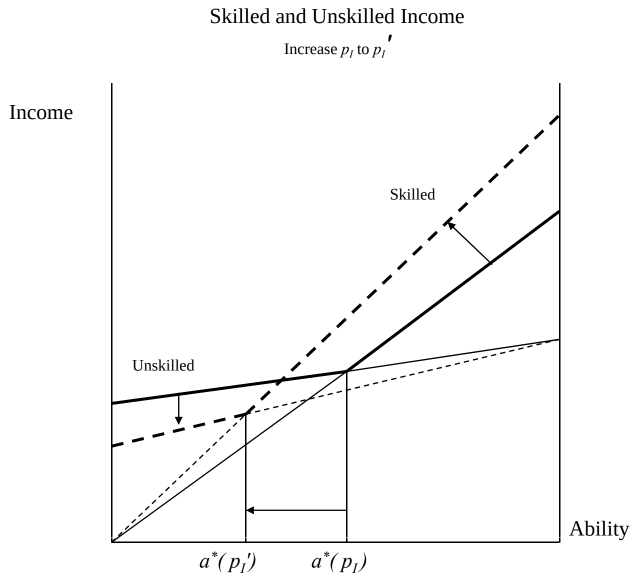

Figure 1.3: Denotes the income for each individual i as a skilled or unskilled worker. Workers maximize income and make their educational decision based on expected income.

ability. Faster rates of technological progress increase the fraction of workers choosing to acquire education:

$$\frac{\partial a_m^*}{\partial p_I} = -\frac{\delta_m \left(1 - p_I^2\right)}{\left(1 - p_I + \left(1 + \delta_m p_I\right) \frac{p_I}{\delta_m} + \delta_m p_I\right)^2} < 0. \tag{1.3.10}$$

The total effective supply of labor is given by aggregating individual labor supplies. This yields

$$\begin{aligned} h_m &= \int_{a_m^*}^1 a_{mi} - \frac{1}{\delta_m}\left(1 - a_{mi}\right) p_I da_{mi} = \frac{1}{2}\left(1 + \frac{p_I}{\delta_m}\right)\left(1 - \left(a_m^*\right)^2\right) - \frac{p_I}{\delta_m}\left(1 - a_m^*\right) \\ l_m &= \int_0^{a_m^*} 1 - \left(1 - a_{mi}\right) p_I da_{mi} = \frac{p_I}{2}\left(a_m^*\right)^2 + a_m^*\left(1 - p_I\right). \end{aligned} \tag{1.3.11}$$

The total effective supply of skilled and unskilled workers is their total labor endowment less the cost of education for skilled workers (first term in the far right equations), less their total learning cost (final term in above equations). The total effective human capital level is given by substituting equations (1.3.11) and (1.3.8) into equation (1.3.5). Rearranging (1.3.5) yields

$$H_m = \left[\frac{1}{2}\left(1+\delta_m p_I\right)\left(1-\left(a_m^*\right)^2\right)+a_m^*\right]-\left[\frac{p_I}{2}\left(\left(1+\delta_m p_I\right)\frac{\left(1-a_m^*\right)^2}{\delta_m}+a_m^*\left(2-a_m^*\right)\right)\right]. \tag{1.3.12}$$

Equation (1.3.12) breaks the overall effective human capital into two primary components. The first set of brackets is the productivity adjusted labor supply of skilled and unskilled workers less the cost of education for skilled workers. The second set of brackets is the productivity adjusted loss of labor supply due to the time spent learning new technologies. The derivative of H_m with respect to p_I is ambiguous and depends on the quality of education. An increase in the rate of technological progress unambiguously increases the first bracket in two ways. First, skilled workers become more productive, and second, more workers make the choice to become skilled. Faster rates of technological progress, however, reduce the term in the second set of brackets because workers spend more time adapting to new technologies rather than in production. This effect is partially offset as more workers become skilled because skilled workers are better able to adapt to new technologies given.

Consider how overall effective human capital depends on p_I:

$$\begin{aligned}\frac{\partial H_m}{\partial p_I} &= \left[\frac{\delta_m}{2}\left(1-a_m^2\right)\right]+\left[\left(1-a_m\left(1+\delta_m p_I\right)\right)\frac{\partial a_m^*}{\partial p_I}\right] \\ &\quad -\left[\frac{1}{2}\left(1+\delta_m p_I\right)\frac{\left(1-a_m^*\right)^2}{\delta_m}+a_m^*\left(2-a_m^*\right)\right]-\left[p_I\left(1-\frac{a_m}{\delta_m}+a_m\left(1+p_I\right)\right)\frac{\partial a_m^*}{\partial p_I}\right]\end{aligned} \tag{1.3.13}$$

The partial derivative $\partial H_m/\partial p_I$ is positive or negative depending on the rate of technological progress and the quality of education. From equation (1.3.13), the first bracket is the gain in productivity for skilled workers, the second bracket is the change in the composition

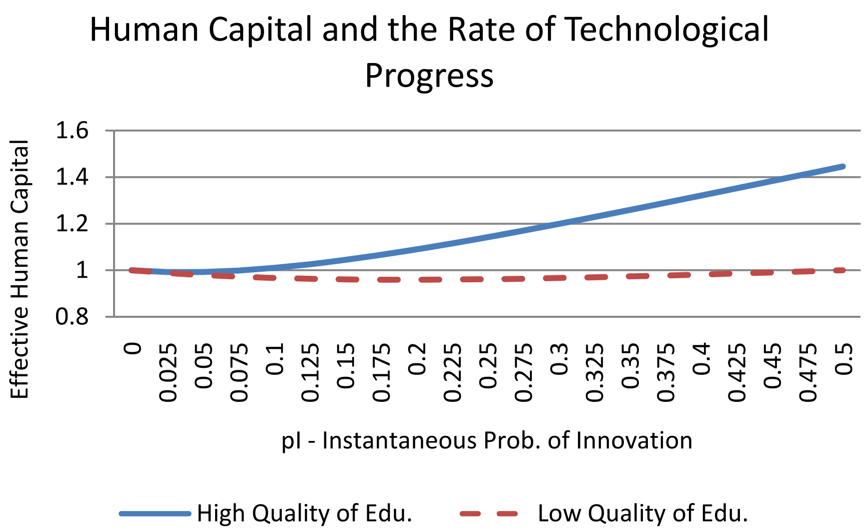

Figure 1.4: Denotes aggregate human capital for a given level of p_I. Parameter values are given below.

of the workforce, the third bracket is the loss due to the increased time needed to adapt to new technologies, and the fourth bracket is the benefit of more skilled workers lowering the overall amount of time workers need to learn new technologies. In addition, a higher quality of education, δ_m, increases the positive impact of the first bracket, ensures that the second bracket is positive, lowers the magnitude of the third bracket and increases the magnitude of the final bracket. Figure 1.4 shows how the effective human capital depends on the interaction of the quality of education and the rate of technological progress.

For the discussion that follows, for a given change in p_I, a country with education parameters such that $\partial H/\partial p_I < 0$ is considered to have a low quality of education, while a country with parameters such that $\partial H/\partial p_I > 0$ is considered to have a high quality of education. Equation (1.3.13) implies that an increase in the rate of technological progress will increase the effective human capital for countries with a sufficiently high quality of education, but could decrease if the quality of education is sufficiently low.

1.3.3 Income Inequality Within Countries

This section derives the relationship between technical innovation, the quality of education, and income inequality within countries. Inequality across countries will be addressed in a subsequent section.

Within country inequality is defined to be the average income of skilled workers relative to the average income of unskilled workers. Exploiting the linearity of incomes with respect to ability, average incomes for skilled, $\tilde{I}_m^s$, and unskilled, $\tilde{I}_m^u$ workers are

$$\begin{aligned} \tilde{I}_m^s &= \tfrac{I_m^s(a_m^*)+I_m^s(1)}{2} = \tfrac{1}{2}w_m^s\left(1+a_m^* - \tfrac{p_I}{\delta_m}\left(1-a_m^*\right)\right) \\ \tilde{I}_m^u &= \tfrac{I_m^u(a_m^*)+I_m^u(0)}{2} = \tfrac{1}{2}w_m^u\left(1+a_m^* - p_I\left(2-a_m^*\right)\right). \end{aligned} \tag{1.3.14}$$

Using the average incomes for the two types of labor, within-country inequality for both the North and South is expressed as

$$\Omega_m^{s/u} = \frac{\tilde{I}_m^s}{\tilde{I}_m^u} = (1+\delta_m p_I)\left(\frac{1+a_m^* - \frac{p_I}{\delta_m}\left(1-a_m^*\right)}{1+a_m^* - p_I\left(2-a_m^*\right)}\right). \tag{1.3.15}$$

1.3.4 Intermediate Goods Sector

The intermediate goods sector follows a two-stage process: 1) the process of research and development; and 2) monopolistic competition given the stage one R&D results. The first stage is the allocation of resources into the research and development (R&D) of new technologies. The North, by assumption, alone possesses the capability to invent a new state-of-the-art technology. If there is R&D success in the North in a given industry j, then the quality of that intermediate good rises by a constant size, q, from q^{k_j} to the new quality level q^{k_j+1}, where k is the number of innovations. Since Northern firms have the ability to create new technologies, they must innovate in order to expand the world's technology frontier. R&D in the South is conducted to imitate frontier technologies.

In the second stage, the successful firms set prices and realize the rents from innovation or imitation. Within intermediate industries, competing firms holding different quality grades of a substitutable intermediate good engage in Bertrand price competition. Under the condition that $q < 1/\alpha$, firms follow a limit price strategy.[10] Following Grossman and Helpman (1991), limit pricing drives lower quality grades within a given industry out of the market.

The location of production for intermediate j depends on the stage one R&D results. Following a successful innovation in industry j, the Northern firm serves as the *global* source for that good. That firm supplies the domestic demand and the foreign demand through exporting. The Northern firm holds the market until either a competing Northern firm makes a further innovation, or the quality grade is successfully imitated by a Southern competitor. Following successful imitation in industry j, the Southern firm serves, again, as the global source by exporting to the North. By assumption, Southern firms have a marginal cost advantage and are able to drive Northern competitors out of the market. Assuming a continuum of industries with a mass of one, n_{NN} is defined as the share of industries served by a firm located in the North whose competitor with the next highest quality grade is a fellow Northern firm, n_{NS} is the share of industries served by a firm located in the North whose competitor with the next highest grade is located in the South, and n_S are the share of industries with production in the South.[11]

Stage 2: Expected Profits

Profits are determined by the type of competition faced by each type of firm. Due to the assumption of nondrastic innovations, firms engage in limit pricing strategies. Bertrand price competition results in prices set just low enough to drive the closest competitor (the firm with the next highest quality grade) out of the market. Northern firms facing Northern competition choose the lowest price at which the previous innovator, or closet competitor, could sell before earning negative profits. Since new innovations are $q > 1$ units more productive than the next best good (in this case held by a competing Northern firm), the

[10] If this inequality does not hold, successful innovators charge monopoly prices and successful imitators engage in limit pricing strategies.

[11] Intermediate producers in the South only face competition from the North. Bertrand price competition drives prices down to marginal costs, thus fellow intermediate firms in the South have no incentive to devote resources to imitate a good that has already been imitated.

innovating firm charges a price q times the marginal cost of their rival in order to completely capture the market for that industry. Northern firms facing Northern competition charge a domestic price $P_{NN} = (q - \epsilon) MC_N = q$, where ϵ is an arbitrarily small positive amount. Notice, the marginal cost of intermediate producers is equal to the price of the final good in that region. In the North, the price of the final good and therefore the marginal cost for intermediate firms in the North is unity, while the price of the Southern final good and marginal costs for Southern intermediate producers adjust to balance trade, $\tilde{P}_S = MC_S < 1$. This price is sufficient to capture the entire market for that industry. In the export market, similar intuition implies $P^*_{NN} = q(1 + \tau_{XS})$, where τ_{XS} is the tariff imposed by the South.

For a Northern firm facing Southern competition, the innovating firm charges a price $q - \epsilon$ over the marginal cost of the Southern competitor. In the Northern market, the effective marginal cost for a Southern firm is $MC_S(1 + \tau_{XN})$, where τ_{XN} is the tariff imposed by the North. Thus, Northern firms facing Southern competition charge the domestic price, $P_{NS} = qMC_S(1 + \tau_{XN}) = q\tilde{P}_S(1 + \tau_{XN})$. In the Southern market, the marginal cost for a Southern firm is simply MC_S, so the export price is $P^*_{NS} = qMC_S = q\tilde{P}_S$.

Finally, Southern firms always face Northern competition, and capture the global market by charging a price $1 - \epsilon$ times the marginal cost of the Northern firm. In the Northern market, the marginal cost for a Northern firm is $MC_N = 1$, and the price is $P^*_j = 1$. In the South, Southern firms price at $P_S = 1 + \tau_{XS}$. Table 1.1 summarizes the limit pricing schedule and the effective marginal cost of production for each type of firm.

The pricing strategies for intermediate firms reveals the role of barriers to trade in the model. Trade liberalization alters the limit prices for the three types of firms, and thus, changes demand, expected profits and ultimately the incentives for innovation and imitation. Rearranging equation (1.3.2) and using Table 1.1, the domestic and foreign demand for each type of firm is given by

Limit Pricing Schedule and Effective Marginal Cost

P_{NN}	$=$	q	MC_{NN}	$=$	1
P^*_{NN}	$=$	$q\left(1+\tau_{XS}\right)$	MC^*_{NN}	$=$	$1+\tau_{XS}$
P_{NS}	$=$	$q\tilde{P}_S\left(1+\tau_{XN}\right)$	MC_{NS}	$=$	1
P^*_{NS}	$=$	$q\tilde{P}_S$	MC^*_{NS}	$=$	$1+\tau_{XS}$
P_S	$=$	$1+\tau_{XS}$	MC_S	$=$	$\tilde{P}_S$
P^*_S	$=$	1	MC^*_S	$=$	$\tilde{P}_S\left(1+\tau_{XN}\right)$

Table 1.1: Summarizes the limit prices for each type of firm in both the domestic and export markets. The effective marginal cost is the true marginal cost of production adjusted for tariffs.

$$
\begin{aligned}
n_{NN} \quad &\Rightarrow \quad X_{NN} = H_N\left(A_N\alpha q^{k_{N_j}\alpha}\tfrac{1}{q}\right)^{1/(1-\alpha)} \\
&\qquad\; X^*_{NN} = L_S H_S\left(A_S\alpha q^{k_{N_j}\alpha}\tfrac{\tilde{P}_S}{q(1+\tau_{XS})}\right)^{1/(1-\alpha)} \\
n_{NS} \quad &\Rightarrow \quad X_{NS} = H_N\left(A_N\alpha q^{k_{N_j}\alpha}\tfrac{1}{q\tilde{P}_S(1+\tau_{XN})}\right)^{1/(1-\alpha)} \\
&\qquad\; X^*_{NS} = L_S H_S\left(A_S\alpha q^{k_{N_j}\alpha}\tfrac{\tilde{P}_S}{q\tilde{P}_S}\right)^{1/(1-\alpha)} \\
n_S \quad &\Rightarrow \quad X_S = L_S H_S\left(A_S\alpha q^{k_{N_j}\alpha}\tfrac{\tilde{P}_S}{1+\tau_{XS}}\right)^{1/(1-\alpha)} \\
&\qquad\; X^*_S = H_N\left(A_N\alpha q^{k_{N_j}\alpha}\tfrac{1}{1}\right)^{1/(1-\alpha)}
\end{aligned}
\tag{1.3.16}
$$

Successful innovators and imitators earn the sum of domestic and export profits. Total profits are

$$
\pi_j = \overbrace{\left(P_j - MC_j\right)X_j}^{\text{Domestic Profits}} + \underbrace{\left(P^*_j - MC^*_j\right)X^*_j}_{\text{Export Profits}}
$$

where P_j, P^*_j, MC_j and MC^*_j are given in Table 2 for $j \in [NN, NS, S]$. I assume trade barriers are sufficiently low that export profits are always positive.

The average expected profits in the North and South are summarized as

$$\pi_N \equiv \bar{\pi}_N Q_N, \text{ where } \frac{\partial \bar{\pi}_N}{\partial \tau_{XS}} < 0, \text{ and } \frac{\partial \bar{\pi}_N}{\partial \tau_{XN}} < 0 \tag{1.3.17}$$

and

$$\pi_S \equiv \bar{\pi}_S Q_N, \text{ where } \frac{\partial \bar{\pi}_S}{\partial \tau_{XS}} > 0, \text{ and } \frac{\partial \bar{\pi}_N}{\partial \tau_{XN}} < 0, \tag{1.3.18}$$

where $\bar{\pi}_N$ and $\bar{\pi}_S$ are the quality adjusted expected profits for firms in the North and South, respectively, and $Q_N = \int_0^1 q^{k_{N_j}\alpha/(1-\alpha)} dj$ is the average quality level on the frontier. Equations (1.3.17) and (1.3.18) are dependent on the barriers to trade, τ_{XS} and τ_{XN}, and the rate of technological progress which is embedded within the effective human capital in the North and South. See the appendix for additional details.

Stage 1: Research & Development

Intermediate firms decide the amount of resources to devote to R&D based on the expected present value of profits for successful research. This, in turn, depends on the probabilities of innovation (I) and imitation (C for copying). This section will draw heavily on the work of Connolly and Valderrama (2005, 2007), most notably by incorporating the concept of "learning-to-learn," which allows for past R&D experience to increase the ability to innovate or imitate.

Let p_{Ik_j} and p_{Ck_j} denote the instantaneous probability of innovation and imitation, respectively, for industry j with current quality level k. The probabilities of research success per unit of time follow a Poisson process depending on the resources devoted to R&D and the quality level in that industry. For the aggregate economy, it is sufficient to characterize the rates of technical progress by looking at the *average* quality. Q_N is the average frontier technology, and Q_S is average quality of Southern intermediates.

In the North, the instantaneous probability of innovation is given by

$$p_I = \phi_I f\left(Q_N\right) Z_N \tag{1.3.19}$$

where ϕ_I is the productivity parameter for the Northern R&D sector, Z_N are the resources devoted to innovative R&D in the North and $f(Q_N)$ is a function that captures the effect of the current technology on the probability of innovation. For simplicity, the function f is defined as

$$f(Q_N) = Q_N^{-1}.$$

This specification captures the idea that new innovations become increasingly complex and, thus, innovation becomes more difficult as the average quality level rises. In-other-words, the easiest innovations are discovered first making it increasingly difficult to innovate over time.

In the South, the instantaneous probability of imitation for the aggregate economy is

$$p_C = \phi_C g(Q_S, Q_N) Z_S \tag{1.3.20}$$

where ϕ_C is the productivity parameter for the Southern R&D sector, Z_S are the average resources devoted to R&D and $g(Q_S, Q_N)$ captures three effects of the current technological environment on the probability of imitation. The first effect is the positive effect of Q_S reflecting learning-to-learn in the South.[12] Higher Q_S implies greater experience with the imitative process which reduces the costs of imitation. The second effect is the increasing difficulty in imitating good of a higher quality. As the frontier expands, innovations are increasingly complex, and costs of imitation increase. Finally, imitation becomes increasingly costly as the aggregate quality in the South catches up to the Northern aggregate quality. The relative quality of the South is defined as $\hat{Q} \equiv Q_S/Q_N$. Intuitively, as the South approaches the North in terms of quality, the pool of potential imitations shrinks, with only the most complex innovations left available for imitation. Thus, the costs of imitation increase as $\hat{Q}$ increases. Considering these three effects, the functional form of g is defined as

$$g(Q_S, Q_N) = Q_S Q_N^{-2} \hat{Q}^{-\sigma} = \hat{Q}^{1-\sigma} Q_N^{-1}$$

[12] For more details on learning-to-learn effects refer to Connolly (2003) and Connolly and Valderrama (2005, 2007).

where $\sigma > 1$ represents how quickly the imitation rates fall as the South approaches the aggregate quality level in the North. The inclusion of $\hat{Q}$ guarantees smooth transitional dynamics. Furthermore, if the South completely catches up to the North in terms of average quality, or $Q_S = Q_N$, the function g is equivalent to the function f.

1.3.5 Income Inequality Across Countries

Total income in each country is the sum of worker income and firm profits. Total per capita income (controlling for the relative size of the South, L_S) is given by

$$\begin{aligned} &\text{North} \quad \Rightarrow \quad \int_0^{a_N^*} I_N^u\left(a_{Ni}\right) da_{Ni} + \int_{a_N^*}^1 I_N^s\left(a_{Ni}\right) da_{Ni} = \left(1-\alpha\right) \bar{Y}_N Q_N \\ &\text{South} \quad \Rightarrow \quad \tfrac{1}{L_S}\left[\int_0^{a_S^*} I_S^u\left(a_{Si}\right) da_{Si} + \int_{a_S^*}^1 I_S^s\left(a_{Si}\right) da_{Si}\right] = \tfrac{1}{L_S}\left[\left(1-\alpha\right)\bar{Y}_S\right] Q_N, \end{aligned} \tag{1.3.21}$$

and total per capita firm profits are given by

$$\begin{aligned} &\text{North} \quad \Rightarrow \quad \left[n_{NN}\bar{\pi}_{NN} + n_{NS}\bar{\pi}_{NS}\right] Q_N \\ &\text{South} \quad \Rightarrow \quad \tfrac{1}{L_S}\left[n_S\bar{\pi}_S\right] Q_N, \end{aligned} \tag{1.3.22}$$

where $\bar{Y}_N = \frac{Y_N}{Q_N}$, $\bar{Y}_S = \frac{Y_S}{Q_N}$, $\bar{\pi}_{NN} = \frac{\pi_{NN}}{Q_N}$, $\bar{\pi}_{NS} = \frac{\pi_{NS}}{Q_N}$, and $\bar{\pi}_S = \frac{\pi_S}{Q_N}$ are the aggregate final goods and profits divided by the aggregate quality index.

In the subsequent analysis, I will focus on two measures of inequality across countries. The first only considers the per capita income of the workers, while the second includes the profits of the firms. Using separate measures of inequality across countries in this way will make the analysis below more clear as to what is driving the dynamics of inequality across countries. Consider the following two measures of inequality across countries:

$$\Omega_1^{N/S} = \frac{\bar{Y}_N}{\frac{1}{L_S}\bar{Y}_S}$$

$$\Omega_2^{N/S} = \frac{(1-\alpha)\bar{Y}_N + n_{NN}\bar{\pi}_{NN} + n_{NS}\bar{\pi}_{NS}}{\frac{1}{L_S}\left[(1-\alpha)\bar{Y}_S + n_S\bar{\pi}_S\right]} \tag{1.3.23}$$

Notice the level of the aggregate quality of intermediate goods has no effect on inequality across countries. In both the North and the South, aggregate output and profits for each type of firm grow at an equal rate of $\frac{\dot{Q}_N}{Q_N}$. Total income and profits in the South are divided by L_S to transform this measure of inequality into per-capita terms.

1.3.6 Consumers

Consumers live in either the North or the South and are immobile across countries. Consumer i makes consumption and savings decisions to maximize the present value of lifetime utility. There is no trade in final goods and so the consumers only have access to domestically produced final goods. The general consumer problem is

$$\max_{C_{mi}, b_{mi}} \int_0^\infty u\left(C_{mi}\right) e^{-\rho t} dt \tag{1.3.24}$$

subject to

$$\dot{b}_{mi} = I_{mi} + r_m b_{mi} - \tilde{P}_m C_{mi}. \tag{1.3.25}$$

where C_{mi} is the consumption of individual i in region m, r_m is the endogenously determined country specific interest rate, I_{mi} is the income for individual i in region m, and b_{mi} is the net assets for person i in region m. Using a constant elasticity of substitution utility function:

$$u\left(C_{mi}\right) = \frac{C_{mi}^{1-\theta} - 1}{1-\theta},$$

the usual expressions for consumption growth are:

$$\frac{\dot{C}_N}{C_N} = \frac{1}{\theta}\left(r_N - \rho\right) \tag{1.3.26}$$

$$\frac{\dot{C}_S}{C_S} = \frac{1}{\theta}\left(r_S - \frac{\dot{\tilde{P}}_S}{\tilde{P}_S} - \rho\right) \tag{1.3.27}$$

where $1/\theta$ is the constant elasticity of substitution for all consumers in both regions. The growth rates of consumption are independent of the individual income level and are equal across all individuals within the region.

1.4 The Steady-State and Transitional Dynamics

1.4.1 The Steady-State

The model is defined by a system of five dynamic equations, given two aggregate resource constraints and the balanced trade condition. In steady-state, the relative aggregate quality level of the South must be constant, or, $\dot{\hat{Q}}/\hat{Q} = 0$; the distribution of intermediate firms must be constant, or, $\dot{n}_{NN} = \dot{n}_{NS} = \dot{n}_S = 0$; and the growth of consumption must equal the growth rate of technology, or, $\dot{C}_N/C_N = \dot{C}_S/C_S = \dot{Q}_N/Q_N$.

Aggregate Resource Constraint and Balanced Trade

Substituting for the prices and demand of intermediate goods, aggregate output for the North and South, respectively, is:

$$Y_N = H_N\Lambda_N\left(\frac{q}{\alpha}\right)\left[n_{NN} + n_{NS}\left(\frac{1}{\tilde{P}_S\left(1+\tau_{XN}\right)}\right)^{\frac{\alpha}{1-\alpha}} + n_S q^{\frac{\alpha}{1-\alpha}}\right] Q_N \tag{1.4.1}$$

$$Y_S = L_S H_S \Lambda_S\left(\frac{q}{\alpha}\right)\left(\frac{\tilde{P}_S}{1+\tau_{XS}}\right)^{\frac{\alpha}{1-\alpha}}\left[n_{NN} + n_{NS}\left(\frac{1+\tau_{XS}}{\tilde{P}_S}\right)^{\frac{\alpha}{1-\alpha}} + n_S q^{\frac{\alpha}{1-\alpha}}\right] Q_N \tag{1.4.2}$$

where $\Lambda_N = A_N^{1/(1-\alpha)}\left(\frac{\alpha}{q}\right)^{1/(1-\alpha)}$ and $\Lambda_S = A_S^{1/(1-\alpha)}\left(\frac{\alpha}{q}\right)^{1/(1-\alpha)}$. The aggregate output in each region is determined, in part, indirectly by the probabilities of innovation and imitation. As with the profit equations, p_I and p_C are embedded within the effective human capital, the balanced trade determination of $\tilde{P}_S$, and the distribution of firms.

The two aggregate resource constraints reflect that the final goods are used for domestic consumption, R&D, or transformed into intermediate goods:

$$\begin{aligned} Y_N &= C_N + X_{NN} + X^*_{NN} + X_{NS} + X^*_{NS} + Z_N \\ Y_S &= C_S + X_S + X^*_S + Z_S \end{aligned} \tag{1.4.3}$$

where $X_{NN} + X^*_{NN}$ is the total intermediate output for Northern firms facing Northern competition supplied to both the domestic and foreign markets. $X_{NS} + X^*_{NS}$ is the total intermediate supply from Northern firms facing Southern competition, and $X_S + X^*_S$ is the total supply of intermediate goods from Southern producers. Tariff revenues are used by the government for no gain in utility or income for the individuals. Using the two resource constraints, I summarize the expressions for Z_N and Z_S as (see the appendix for details)

$$Z_N = Y_N - C_N - (X_{NN} + X^*_{NN} + X_{NS} + X^*_{NS}) \equiv \bar{Z}_N Q_N \tag{1.4.4}$$

and

$$Z_S = Y_S - C_S - (X_S + X^*_S) \equiv \bar{Z}_S Q_N \tag{1.4.5}$$

where $\bar{Z}_N$ and $\bar{Z}_S$ are the quality adjusted expenditures on R&D.

The relative price of the Southern final good, $\tilde{P}_S$, adjusts to balance trade at all times. The trade balance equates the value of Northern intermediate good exports and the value of intermediates produced in the South and exported to the North,

$$\text{TB} = \overbrace{P^*_{NS} n_{NS} X^*_{NS} + P^*_{NN} n_{NN} X^*_{NN}}^{\substack{\text{Value of} \\ \text{N. Exports}}} - \underbrace{P^*_S n_S X^*_S}_{\substack{\text{Value of} \\ \text{S. Exports}}} = 0. \tag{1.4.6}$$

Equation (1.4.6) implicitly solves for the relative prices of the Southern final goods, $\tilde{P}_S$. See the appendix for additional details.

Relative Quality Level of the South

Using the definition of $\hat{Q} = Q_S/Q_N$, the relative average quality of the South evolves according to

$$\frac{\dot{\hat{Q}}}{\hat{Q}} = \left(q^{\frac{\alpha}{1-\alpha}} - 1\right)(p_C - p_I). \tag{1.4.7}$$

In steady-state the evolution of the relative Southern quality level is constant. Therefore the steady-state probability of innovation is exactly that of the probability of imitation, or, $p_I = p_C$.

Distribution of Intermediate Firms

Consider, first, the fraction of industries characterized by Northern firms facing Northern competition, n_{NN}. The share of this type of firm will fall if a technology level is imitated, as the production shifts to the South. The share of Northern firms facing Northern competition increases with an innovation over a Northern firm previously facing Southern competition, provided that technology is not imitated. These dynamics are captured in equation (1.4.8). The share of Northern firms facing Southern competition increases through innovation in the industries where production is currently in the South (n_S), but will fall through imitation or further innovation. This is detailed in equation (1.4.9). Finally, the share of firms located in the South increases through imitation in any industry where production is currently in the North ($n_{NN} + n_{NS}$) and falls with successful innovation, as captured in equation (1.4.10).

$$\dot{n}_{NN} = p_I(1 - p_C)\,n_{NS} - p_C n_{NN} \tag{1.4.8}$$

$$\dot{n}_{NS} = p_I(p_C n_{NN} + n_S) - [(1 - p_I)\,p_C + p_I(1 - p_C)]\,n_{NS} \tag{1.4.9}$$

$$\dot{n}_S = (1 - p_I)\,p_C(n_{NN} + n_{NS}) - p_I n_S \tag{1.4.10}$$

In steady-state, $\dot{n}_{NN} = \dot{n}_{NS} = \dot{n}_S = 0$. Solving the system of equations, the steady-state share of each type firm is

$$\begin{aligned} n_{NN} &= \frac{p_I^2(1-p_C)}{(p_I+p_C-p_Ip_C)^2} \\ n_{NS} &= \frac{p_Ip_C}{(p_I+p_C-p_Ip_C)^2} \\ n_S &= \frac{p_C(1-p_I)}{p_I+p_C-p_Ip_C}. \end{aligned} \tag{1.4.11}$$

Using the steady-state result of the equalization of p_I and p_C, the steady-state shares of each type of firm (setting $p = p_C = p_I$) is

$$\begin{aligned} n_{NN} &= \frac{1-p}{(2-p)^2} \\ n_{NS} &= \frac{1}{(2-p)^2} \\ n_S &= \frac{1-p}{2-p}. \end{aligned} \tag{1.4.12}$$

A steady-state increase in the probability of innovation and imitation yields an increase in the share of Northern firms facing Southern competition, or in other words, an increase in global competition. Furthermore, the share of Northern firms facing Northern competition and the share of firms located in the South both decrease.

Consumption and Technological Growth

From equations (1.3.26) and (1.3.27), the growth rates of consumption depend on the country-specific interest rate and the evolution of the relative price of the Southern final good, $\dot{\hat{P}}_S$, as determined by the balanced trade condition. To determine r_N and r_S, two free-entry conditions imply that firms will devote resources to research until the expected value of R&D success equals the R&D costs for the average industry. The Northern and Southern free entry conditions, respectively are

$$p_I \pi_N \int_t^\infty e^{-\int_t^s [r_N(v)+p_C(v)+p_I(v)]dv} ds = Z_N$$
$$(1.4.13)$$
$$p_C \pi_S \int_t^\infty e^{-\int_t^s [r_S(v)+p_I(v)]dv} ds = Z_S$$

The expected value of innovation is the probability of R&D success times the average profits discounted by the interest rate and the probability of rival innovation and Southern imitation. The Southern profits are discounted only by the interest rate and the probability Northern innovation. Differentiating both sides of the free entry conditions using Leibniz's rule yields the interest rates in both countries:

$$r_N = \frac{p_I \pi_N}{Z_N} + \frac{\dot{Z}_N}{Z_N} - \frac{\dot{p}_I}{p_I} - \frac{\dot{\pi}_N}{\pi_N} - p_C - p_I \qquad (1.4.14)$$

$$r_S = \frac{p_C \pi_S}{Z_S} + \frac{\dot{Z}_S}{Z_S} - \frac{\dot{p}_C}{p_C} - \frac{\dot{\pi}_S}{\pi_S} - p_I \qquad (1.4.15)$$

The interest rates determine, in the long run, the rate of growth for output, consumption, and research expenditures in both countries.

The final dynamic expressions represent the conditions for balance growth. Let $\chi_N \equiv C_N/Q_N$ and $\chi_S \equiv C_S/Q_N$ denote the quality adjusted consumption. In steady state, the rate of consumption growth equals the growth rate of the frontier technology level, or $\frac{\dot{\chi}_N}{\chi_N} = \frac{\dot{\chi}_S}{\chi_S} = 0$. The expressions for the North and South, respectively are

$$\frac{\dot{\chi}_N}{\chi_N} = \frac{1}{\theta}(r_N - \rho) - \left(q^{\frac{\alpha}{1-\alpha}} - 1\right) p_I \qquad (1.4.16)$$

$$\frac{\dot{\chi}_S}{\chi_S} = \frac{1}{\theta}\left(r_S - \frac{\dot{\tilde{P}}_S}{\tilde{P}_S} - \rho\right) - \left(q^{\frac{\alpha}{1-\alpha}} - 1\right) p_I. \qquad (1.4.17)$$

As a result, in steady-state the change in the relative price of the Southern final good, $\frac{\dot{\tilde{P}}}{\tilde{P}}$, is zero, thus, the diffusion of technology from the North to the South is sufficient to equalize the interest rates in the North and South, or $r_N = r_S$ in steady-state.

1.4.2 Summary of Steady State

In steady state:

1. $p_C = p_I$ based on equation (1.4.7).

2. The distribution of firm types are pinned down by equation (1.4.12).

3. The balanced trade condition pins down the relative price of the Southern final good, $\tilde{P}_S$ by equation (1.4.6).

4. The resource constraints in the North and South pin down R&D outlays, Z_N and Z_S, by equations (1.4.4) and (1.4.5).

5. The interest rates in the North and South are determined by the free entry conditions.

6. The balanced growth condition for the south, equation (1.4.17), pins down the relative technology level in the South, $\hat{Q}$.

7. The instantaneous probability of Northern innovation is pinned down by the balanced growth condition in the North.

1.4.3 Transitional Dynamics

The dynamic system of five equations and five unknowns consist of the evolution of $\hat{Q}$, defined by equation (1.4.7); two firm entry and exit conditions, defined by equations (1.4.9) and (1.4.10); and the consumption growth conditions in the North and South, defined by equations (1.4.16) and (1.4.17) respectively. Using initial conditions for $\hat{Q}$, n_{NS}, and n_S, the transitional dynamics of wage inequality in the North and South are fully characterized. The transition path is solved by log-linearizing the system of equations around the steady-state and using the reverse shooting methodology.

The model is solved using numerical simulation for reasonable parameter values. Parameter values are based on theoretical and empirical priors, and chosen such that they yield saddle path stability. In addition, I select parameters such that in steady state and at all points during the transition that $0 < p_I < 1$, $\frac{1+\tau_{XS}}{q} < \tilde{P}_S < 1$, and $0 < \hat{Q} < 1$.

Parameter Values		
θ	$= 3.0$	Inverse of constant elasticity of sub.
ρ	$= 0.02$	Subjective discount rate
α	$= 0.3$	Capital share in final goods production
σ	$= 8.5$	Elasticity of p_C w.r.t. $\hat{Q}$
A_N	$= 2.25$	Northern final goods productivity
A_S	$= 1.75$	Southern final goods productivity
ϕ_I	$= 0.15$	Northern innovation productivity
ϕ_C	$= 0.075$	Southern imitation productivity
q	$= 1.5$	Constant size of quality improvements
L_S	$= 2.0$	Relative size of the South

Table 1.2: Qualitative results are robust to small changes in the quality of education parameters.

Other parameter selections potentially lead to non-existent steady-states, or globally divergent transitional paths. The parameters are restricted as to yield saddle paths with all real eigenvectors and three negative eigenvalues in the transitional matrix. See Eicher and Turnovsky (2001) and Connolly and Valderrama (2007) for details. The benchmark parameter values are listed in Table 1.2.

The parameter values for the trade barriers, τ_{XS} and τ_{XN}, and quality of education, δ_m are discussed in the next section.

1.5 Southern Trade Liberalization

Assume the global economy is in a steady-state in which there are positive tariffs on Southern intermediate imports, τ_{XS}. For simplicity, I set $\tau_{XN} = 0$.[13] Trade liberalization removes the barriers to trade, specifically τ_{XS} drops from $\tau_{XS} = 0.35 \Rightarrow 0.0$.[14]

I differentiate between two cases based on the quality of education in the South. In the first case I assume a low value for quality of education parameter δ_S^{low}, and in the second

[13] Northern trade liberalization and bilateral trade liberalization experiments are possible, however, I focus here on Southern trade liberalization.

[14] Trade liberalization of a lesser magnitude induces the same qualitative results.

Quality of Education Parameters

	North	South (Case 1)	South (Case 2)
δ	19.5	5	10.5

Table 1.3: Denotes quality of education parameters. Qualitative results are robust to small changes in the quality of education parameters. The change in the quality of education in the South is the only difference between Case 1 and Case 2.

case the South has a higher quality of education, δ_S^{high}. In both cases I assume the North has a higher quality of education, and it follows that $\delta_N \geq \delta_S^{high} > \delta_S^{low}$. The quality of education in the South is the only difference between case one and case two. Table 1.3 summarizes the quality of education parameters. The quality of education in the South is the only difference between the two cases.

1.5.1 Steady State Implications

The long run implications of Southern trade liberalization do not significantly change based on the quality of education in the South. In steady state, Southern trade liberalization unambiguously increases the incentives to innovate in the North. The average profits of Northern intermediate firms are decreasing in the level of the Southern tariff. Intuitively, the effective marginal cost of a Northern firm exporting to the Southern market falls when the tariff rate is reduced, which increases the returns to successful innovation.

The faster long run rate of technological progress increases within country inequality in both the North and the South, increases the total per capita income for Southern workers relative to Northern workers, and also increases (to a lesser amount) the total relative income of the South when also considering the profitability of Northern and Southern intermediate firm profits. As mentioned above, profits for Northern firms rise which also increases the total fraction of firms located in the North. In addition, profits for Southern firms fall as does the fraction of firms located in the South. Intuitively, lower trade barriers imply Southern

Steady State Results

	Case 1: Low Quality			Case 2: High Quality		
Variable	Original SS	Final SS	Change	Original SS	Final SS	Change
$p_I = p_C$	0.00641	0.01013	58.03	0.006374	0.010045	57.6
$\hat{Q}$	0.935	0.856	-8.45	0.936	0.859	-8.23
H_N	1.00378	1.01135	0.75	1.00372	1.01115	0.74
H_S/L_S	0.99730	0.99617	-0.11	0.99893	1.00005	0.11
a_N^*	0.88825	0.83379	-6.13	0.88886	0.83491	-6.07
a_S^*	0.96878	0.95144	-1.79	0.93693	0.90381	-3.53
$\Omega_N^{s/u}$	1.06596	1.1044	3.61	1.06556	1.10357	3.57
$\Omega_S^{s/u}$	1.0193	1.03054	1.10	1.03677	1.05808	2.06
$\Omega_1^{N/S}$	1.64440	1.53599	-6.59	1.64257	1.53190	-6.74
$\Omega_2^{N/S}$	1.67205	1.64945	-1.35	1.66928	1.64274	-1.59

Table 1.4: See text for parameters used before and after Southern trade liberalization.

firms must charge a low price to ensure all Northern firms are priced out of the market.

Table 1.4 details the steady state implication of Southern trade liberalization using the parameters above.

Southern trade liberalization significantly increases the rate of technological progress in both cases. When the South has a high quality of education, within country inequality increases by a slightly larger percent in the long run, and using both measurements of across country inequality, a higher quality of education leads to greater convergence. There is a greater amount of additional workers who choose to become skilled when the quality of education is high. Finally, when the quality of education is low, trade liberalization decreases the overall effective human capital in the South, but when the quality of education is high, trade liberalization increases overall effective human capital.

1.5.2 Dynamic Transition

The quality of education in the South does not greatly change the long implications for inequality following trade liberalization. However, the transitional dynamics depend on the quality of education to a much larger extent. I begin, first, by discussing the dynamics of the instantaneous probabilities of innovation and imitation, and then shift my focus to the dynamics of within and across country inequality. The dynamics of all variables are found in the appendix.

Probabilities of Innovation and Imitation

Figure 1.5 documents the evolution of the rates of innovation and imitation in the transition from the initial steady state with barriers to trade to the open steady-state as the percentage deviation from the initial steady state.

Beginning with the immediate effects, trade liberalization reduces the price of intermediate goods for the Southern final goods market in two ways, $P_{NN}^{*} = q\,(1 + \tau_{XS})$ and $P_S = 1 + \tau_{XS}$, thus increasing the demand from the South. Overall, average profits of intermediate good firms in the North increase, which leads to an increase the resources allocated for innovation. The fall in P_{NN}^{*} increases the demand for exports from Northern firms facing Northern competition, X_{NN}^{*}, which decreases the relative price of the Southern final good, $\tilde{P}_S$. The fall in $\tilde{P}_S$ increases Y_N by equation (1.4.1), decreases $\bar{\pi}_N$ and decreases X_{NN}^{*}. The net total initial effect is an immediate jump in Z_N, and thereby, an increase in p_I. In the South, trade liberalization reduces average profits for successful imitators, and through the balance trade condition, reduces aggregate output, Y_S by equation (1.4.2). The net initial effect is a small drop in the probability of imitation p_C. These initial jumps hold in both the case when the quality of education is high and when the quality of education is low.

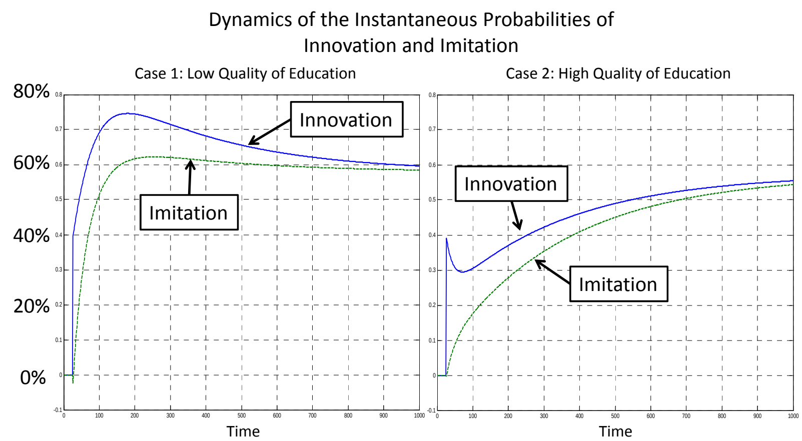

Figure 1.5: Denotes the transitional dynamics of the instantaneous rates of innovation and imitation following Southern trade liberalization. Given as the percentage change from the initial steady state.

The initial increase in the rate of innovation (p_I) and decrease in the rate of imitation (p_C) also have implications for the effective human capital in both regions. The effective human capital increases in the North, and decreases in the South when the quality of education in the South is low, which, by equation (1.4.4), increases Northern aggregate output, and decreases in Southern output which further increases the resources allocated to innovation in the North. This leads to a larger initial gap between p_I and p_C when the quality of education in the South is low.

The initial jump in p_I introduces a dynamic feedback loop. When the quality of education in the South is low, H_S falls, which lessens their ability to successful imitate. Lower rates of imitation extend the duration of Northern firms earning profits, which continues to increase their incentives to innovate. The effective human capital in the North continues to rise, further increasing effective human capital in the North, while the effective human capital in the South continues to fall, further decreasing their ability to imitate. The complete transitional path, however, is non-monotonic. Since p_I is greater than p_C in the transition, $\hat{Q}$ decreases. As $\hat{Q}$ falls, successful imitation becomes easier by equation 1.3.20, and the rate

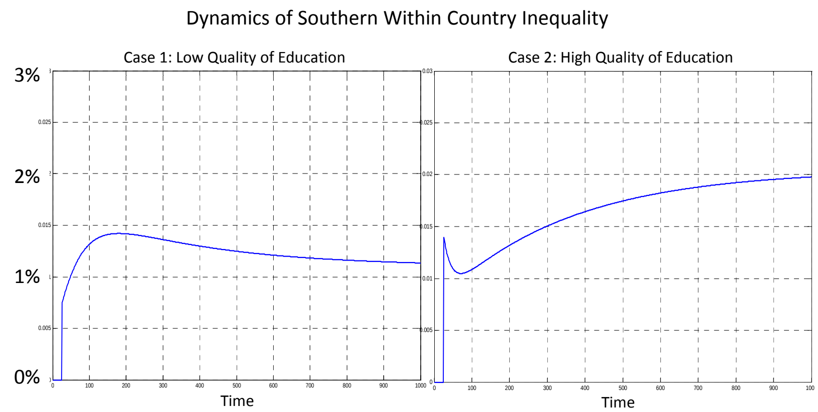

Figure 1.6: Denotes the transitional dynamics of income inequality within the South following Southern trade liberalization. Given as the percentage change from the initial steady state.

of imitation begins to converge to the rate of innovation. As a result p_I begins to fall as the transitional path approaches the new long run steady state.

A very different feedback loop emerges when the quality of education in the South is high. The initial jump in p_I increases the effective human capital in the South when their quality of education is high. This increases their ability to imitate, which decreases the incentives for Northern firms to innovate following the initial jump following trade liberalization. The fall in p_I during the first part of the transition along with the growth in p_C makes imitation increasingly difficult. Thus, p_C increases by a smaller and smaller amount, which then reverses the downward movement of p_I. During the last part of the transition, both p_I and p_C converge to a higher steady state.

Southern Within Country Inequality

Figure 1.6 documents Southern income inequality within countries for case 1 (low quality of education) and case 2 (high quality of education). The two diagrams are in scale as percentage deviation from the initial steady state.

The dynamics of within country inequality follow the same nonmonotonic transition path as the instantaneous probability of innovation. As mentioned above, the steady state growth of inequality is higher when the quality of education is high. This conceals, however, the important differences during the transition. During the transition, the growth of inequality is higher when the quality of education is low. In addition, after an initial jump, inequality is declining during the first part of the transition when the quality of education is high, whereas, inequality continues to increase when the quality of education is low.

Inequality Across Countries

In the model I characterize income inequality in two ways, the first considers only the relative per capita income of workers, while the second takes into account the total profits of firms. Using either measurement Southern trade liberalization decreases long run inequality across country. Figure 1.7 shows the percentage change of the per capita income of Northern workers relative to Southern workers, and Figure 1.8 includes firm profits. A decline in either measurement indicates convergence by the South (relative income of Northern workers decline).

Focusing first on Figure 1.7, income inequality across countries falls immediately following Southern trade liberalization. In the first part of the transition inequality rises, before falling to a lower long run steady state. This holds true for when the quality of education in the South is low or high. In the long run, inequality falls by a slightly greater amount when the quality of education is low. However, the differences in the transition are equally important. The divergence during the first part of the transition is stronger when the quality of education is low compared to the case when the quality of education is high.

This become more clear when looking at Figure 1.8 where firm profits are included. Overall, inequality across countries decreases by a smaller amount. This is driven by an increase in the number of firms in the North and their increased profitability due to trade liberalization. Using this measurement, inequality across countries decreases by a larger amount when the quality of education in the South is high. Moreover, the decline in inequality is monotonic. When the quality of education in the South is low, inequality increases in the

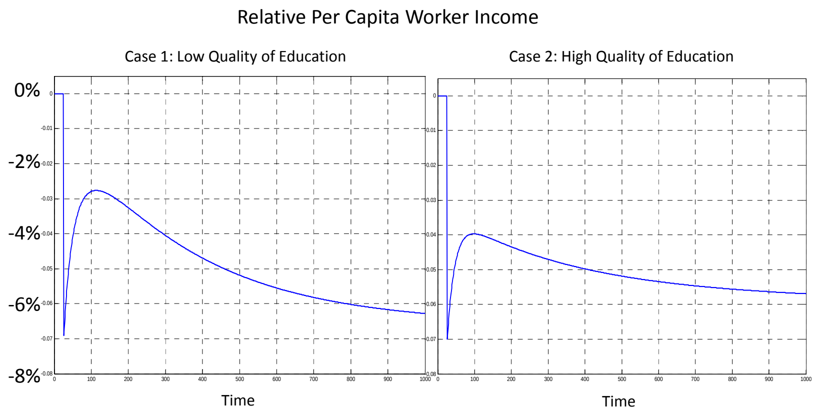

Figure 1.7: Denotes the transitional dynamics of income inequality across countries following Southern trade liberalization, captured of the total income per worker in the North relative to that in the South. Given as the percentage change from the initial steady state.

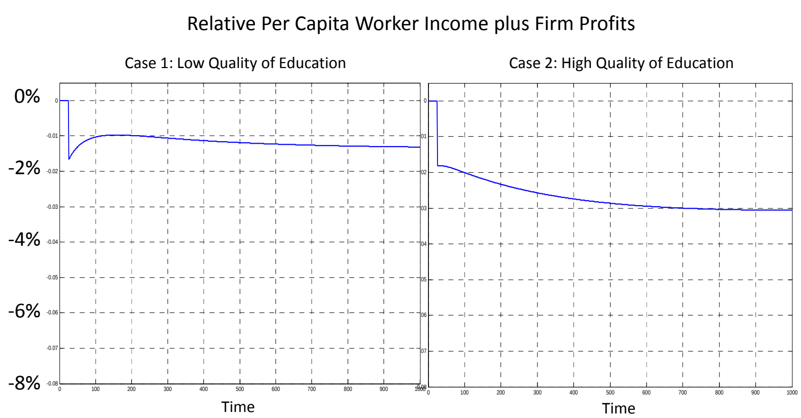

Figure 1.8: Denotes the transitional dynamics of income inequality across countries following Southern trade liberalization, captured of the total income per worker plus total firm profits in the North relative to that in the South. Given as the percentage change from the initial steady state.

initial periods of the transition following the immediate impact of trade liberalization.

1.6 Conclusion

This paper emphasizes how the dynamics of income inequality, both within and across countries, are dependent on the interaction between the rate of new technologies entering the production process and the quality of education embedded within the effective human capital. This paper links the two types of inequality within a general equilibrium model of North-South trade and endogenous innovation and imitation, in which agents make the endogenous discrete choice of educational attainment. The quality of education increases the ability of workers (who acquired education) to adapt and learn new technologies. Following Southern trade liberalization, the ability to adapt to faster rates of technological progress has implications for the long run, but more importantly, the short run, dynamics of within and across country income inequality.

In the long run, Southern trade liberalization increases the rate of technological progress, which increases inequality within both the North and the South. In the transition, however, income inequality in the South will increase by a greater percentage when the quality of education is low. In terms of inequality across countries, the total per capita income of Southern workers and firm profits increase relative to the North. This suggests Southern trade liberalization decreases long run inequality across countries. This convergence is stronger when the quality of education in the South is high. When the quality of education is low, there are periods of divergence during the dynamic transition that does not appear when the quality of education is high. The key contribution of this paper is introducing a source of heterogeneity among developing countries that accounts for a wide array of income inequality dynamics.

Broadly speaking, the results provide some intuition as to why, following trade liberalization, developing countries in Latin America and Africa, with a relatively low quality of education have experienced a higher growth of within country income inequality and notably less convergence compared to East Asian economies. In the next chapter, I will provide empirical support for the relationship between within country inequality, technological change and the quality of education. Specifically, he finds a higher quality of education directly reduces the growth of inequality and indirectly by reducing the marginal impact of faster rates of technological progress. This empirical evidence lends support that emphasize the critical role of education and technological change in determining the dynamics of income inequality.

2. The Diffusion of Technology, Education and Income Inequality: Evidence from Developed and Developing Countries

2.1 Introduction

In recent decades, rapid technological progress has coincided with fundamental changes to the dynamics of income inequality in countries across the development spectrum. The growth of inequality accelerated substantially within developed countries and most developing countries during the 1980s and 1990s. Across developing and emerging economies, the growth in inequality was more severe in Latin America and Africa compared to many East Asian countries.[1] This paper uses a broad spectrum of developed and developing countries to investigate the factors underlying the recent dynamics of income inequality. This empirical analysis shows that the diffusion of new technologies contributed significantly to the growth of inequality. In addition, this paper also shows that the quality of education directly lowers the growth of inequality, but also significantly reduces the impact of new technologies on inequality. The quality of education emerges as an important determinant as to why the dynamics of inequality differed among developing countries.

Since Kuznets' (1955) seminal work, the relationship between inequality and technological progress has been widely researched and documented. The recent rise in income inequality is largely attributed to Skill Biased Technological Change (SBTC).[2] Nelson and Phelps (1966), for example, contend that during periods of rapid technological change, skilled workers are quicker to obtain the additional knowledge required to adapt to new technologies, which in turn, increases the skill premium.[3] Other theories such as capital-skill complementary (Greenwood et al., 1997; Krusell et al., 2000) or directed technological change (Acemoglu, 1998; 2002) have been proposed that link technological change to income

[1] The measure for inequality is the Theil index from the University of Texas Inequality Project (available at http://utip.gov.utexas.edu/data.html).

[2] For surveys see Acemoglu (2002) and Aghion (2002), among others.

[3] Also see Greenwood and Yorukoglu (1997), Caselli (1999), Galor and Moav (2000) and Aghion (2002) for similar arguments.

inequality. The empirical evidence is mixed at best. Bound and Johnson (1992), Juhn, Murphy and Pierce (1993), Levy and Murnane (1992), Katz and Murphy (1992), Katz (1999) and others find a positive link between technological progress and inequality in the U.S., while Berman, Bound and Machin (1998) find evidence SBTC throughout other developed countries. Card and DiNardo (2002), on-the-other-hand, review the literature and conclude that technology only plays a small role in the growth of inequality. Much of the empirical literature, however, has dealt with SBTC largely within only OECD countries (Autor and Katz, 1999). This paper extends the literature to consider the links between new technologies, education and the dynamics of inequality for a broader spectrum of developed and developing countries.

The main contribution of this paper consists of linking how the dynamics of inequality respond to the interaction of technological change with both the quantity and quality of education. I capture the diffusion of new technologies by utilizing a theoretically consistent gravity model to estimate the high skill factor content of imports. Using the Theil index (UTIP-UNIDO, 2002) to measure income inequality, I find that a higher skilled factor content of imports significantly increase the growth of inequality, but the magnitude of this effect is smaller when the quality of education is high. In addition, the interaction between technological change and the quantity of education is insignificant. This suggests that during periods of accelerated technological progress, a higher quality of education (rather than a higher quantity of education) lessens the impact of new technologies on the growth of inequality.

This paper is the first to consider the impact of the *quality* of education on the dynamics of inequality. De Gregorio and Lee (2002) use a sample of developed and developing countries and find the level of inequality to be negatively related to both the average years of education and a more equitable distribution of education. However, one year of education may differ dramatically in terms of quality across countries. Hanushek and Kimko (2000) develop quality of education measures using internationally comparable math and science test scores to capture the large dispersion of the quality of education throughout the world. This paper demonstrates that the quality of education is important factor that lessens the effect of new technologies on the growth of inequality. A labor force with a higher quality of education is quicker to adapt to new technologies. This intuition is consistent with the Nelson and Phelps theory where the ability to learn new technologies is the link between technological change and growing income inequality.

To estimate the change in the arrival rate new technologies for a broad range of economies, this paper isolates the high skill component of imports.[4] Intuitively, during periods of trade liberalization a higher skill content embodied within imports leads to a faster change in the arrival rate of new technologies. This measure is advantageous for several reasons. First, it provides a measure of technological change for over 100 countries across the development spectrum. Second, most countries engaged in widespread trade liberalization during the 1980s and 1990s, and evidence suggests that imports are a significant channel of technological diffusion (Keller, 2004).[5] New communication and information technologies diffused not only throughout the industrialized countries, but also to developing countries as well, largely through imports.[6]

The median growth of inequality during the 1980s was positive in Latin America, Africa, Asia, the Middle East/North Africa, and advanced countries. The magnitude of this growth was most severe in Latin America and Africa, and the lowest in Asia. I find the interaction between technological change and the quality of education to be fundamental in explaining the variations in the observed dynamics of income inequality in developing countries. The results show that the predicted growth of inequality to be 39 percent in Latin America between 1980 and 1990 compared to just 16 percent in Asia. This is driven by a substantially

[4]Other measures for technological change have included computer use (Krueger, 1993; Reilly, 1995; Card, Kramarz and Lemieux, 1999; Autor, Katz and Krueger, 1998; Riley and Young, 1999; Haskel and Heden, 1999; Desjonqueres, Machin and van Reenen, 1999), capital intensities (Krusell et al., 2000; Goldin and Katz, 1998), investment in research and development (R&D) (Tan and Batra, 1997), and R&D intensity (Dickens and Katz, 1987; Machin and van Reenen, 1998), among others. These measurements for technological change, in general, show a positive link between technology and inequality, however limited international data confines studies to the U.S. and other developed countries.

[5]For example, employing foreign intermediate goods involves the implicit knowledge of using the technology embedded within imports. In addition, the diffusion of technology raises the productivity of the research in the recipient country, which implies an international research spillover.

[6]Consistent with the notion of major technological change in reference to General Purpose Technologies (See Helpman, 1998; Aghion and Howitt, 1998; Galor and Tsiddon, 1997; Galor and Moav, 2000; and Aghion, 2002).

higher quality of education, on average, in Asia. Given that the average years (quantity) of education was actually higher in Latin America relative to Asia in 1980, it is the quality, not quantity, of education that potentially explains the diverse patterns of inequality among developing countries.

The remainder of the paper is organized as follows: Section 2.2 presents a theoretical model to motivate the empirical specification; Section 2.3 details the data, including the measurement of the skilled factor content of trade; Section 2.4 presents the empirical results; and Section 2.5 concludes.

2.2 The Quality of Education and Technological Progress

2.2.1 Model Setup

Skill biased technological change is modeled in many ways. This paper makes straightforward extensions to the formulation of SBTC in Bound and Johnson (1992), Autor, Katz, and Krueger (1998), and Card and DiNardo (2002). This class of models allows for heterogeneous productivities among different skill groups. This paper, in line with the ideas of Nelson and Phelps (1966), Galor and Moav (2000) and Aghion (2002), modifies the set up to allow for the arrival rate of new technologies to affect not only the relative demand for high skill workers, but also the effective efficiency units of labor supply.

Consider a simple CES production function with two factors of production: high skill (h) and low skill (l) workers,

$$Y = A\left[(g_h N_h)^{\rho} + (g_l N_l)^{\rho}\right]^{1/\rho}, \tag{2.2.1}$$

where N_h and N_l are the aggregate *efficiency units* of high and low skill workers, g_h and g_l denote the productivities of high and low skill workers, and A is a skill neutral technology parameter. The elasticity of substitution between high and low skill workers is $\sigma = \frac{1}{1-\rho}$. [7]

[7] Johnson (1997) suggests the elasticity of substitution lies somewhere between 1 and 2, with a best guess to be in the neighborhood of 1.4 - 1.5. This implies ρ to be around 0.3. Also see Katz and Murphy (1992), Krusell et al. (2000), and Autor, Katz and Krueger (1998).

2.2.2 Labor Demand

Using equation (2.2.1), the inverse demand functions for efficiency units of high and low skill workers are given by

$$\begin{aligned} w_h &= \bar{w} g_h^{\rho} N_h^{\rho-1} \\ w_l &= \bar{w} g_l^{\rho} N_l^{\rho-1}, \end{aligned} \tag{2.2.2}$$

where $\bar{w} = A\left[(g_h N_h)^{\rho} + (g_l N_l)^{\rho}\right]^{1/\rho - 1}$, and w_h and w_l denote the wages for high and low skill workers respectively.

The ratio of marginal products of the two types of labor presents a measure of income inequality as a function of relative productivity, relative efficiency units of labor and the elasticity of substitution. The relative wage is given by

$$\frac{w_h}{w_l} = \left(\frac{g_h}{g_l}\right)^{\rho} \left(\frac{N_h}{N_l}\right)^{-(1-\rho)}. \tag{2.2.3}$$

An increase in the relative productivity of high skill workers increases the relative wage, while an increase in the relative supply of skilled efficiency units decreases the relative wage.

Skill biased technological change involves an increase in the relative productivity of the high skill workers, $\frac{g_h}{g_l}$. There are, however, many methods to modeling SBTC. One line of reasoning considers capital and skills to be compliments. In this case innovations that reduce the cost of capital, in turn, increase the relative productivity of skilled workers. Goldin and Katz (1998) and others find evidence that skills and capital are indeed compliments. Acemoglu (1998, 2002) argues that it is not only the speed of innovations, but also the direction of technological change. This theory suggests the expansion of educated labor during the postwar period caused new technologies to be more directed toward educated workers. This effect, again, changes the relative productivity and relative demand for high skill workers.

This paper introduces SBTC in line with the Nelson-Phelps view of human capital. During periods of rapid technological diffusion, the relative demand for skilled workers increases reflecting their advantage of adapting to new technologies. Galor and Moav (2000) presents a model in which the rate of technological progress determines the relative demand for high skill workers. In line with Galor and Moav, equation (2.2.3) is modified such that the relative demand for high skill workers is driven by the arrival rate of new technologies. Let $0 < \bar{a} < 1$ denote the exogenous rate of the diffusion of new technologies. A simple formulation is

$$\frac{g_h}{g_l} = f\left(\bar{a}\right) = 1 + \bar{a}$$

where the function f is increasing in the arrival rate of new technologies, or $f'\left(\bar{a}\right) > 0$, reflecting greater demand for high skill workers during periods of faster technological diffusion. Rewriting (2.2.3) with this substitution yields a function for the relative demand for skilled workers,

$$\frac{w_h}{w_l} = \left(1 + \bar{a}\right)^{\rho} \left(\frac{N_h}{N_l}\right)^{-(1-\rho)}. \tag{2.2.4}$$

An increase in the arrival rate of new technologies leads to an increase in the relative wages of high skill workers (holding constant the supplies of efficiency units of labor), which reflects their advantage of learning new technologies.

2.2.3 Labor Supply

The arrival rate of new technologies can also have an impact on the efficiency units of labor supply. For a given arrival rate of new technologies, $\bar{a}$, a worker must spend a certain portion of their time learning and adapting to the new technologies, away from wage earning production. If new technologies begin arriving at a faster rate, that same worker must take more time in the process of learning the technologies. This effect reduces the efficiency units of labor supplied to production. This component of the model reflects empirical evidence from Bartel and Sicherman (1998), who show that an increase in the rate of technological progress increases the need to (re)train workers, especially low skill workers. Allowing the rate of technological progress to alter the effective labor supply also introduces the important role of educational factors. All else equal, a worker with more years of education or a better quality of education is able to learn the new technologies at a faster rate.

Let $\beta > 1$ represent the quality of education and $T > 1$ denote the baseline quantity of education received by all workers. Skilled workers are assumed to have a relative advantage at adapting to, or learning, new technologies, captured by the exogenous parameter $x > 0$. The efficiency units of high and low skill workers are given by

$$N_h = n_h \left(1 - \frac{\bar{a}}{\beta T\,(1+x)}\right) \tag{2.2.5}$$

$$N_l = n_l \left(1 - \frac{\bar{a}}{\beta T}\right), \tag{2.2.6}$$

where n_h and n_l are the numbers of each type of worker, and the term in the parenthesis (between 0 and 1) captures the notion that efficiency units of supply depreciate based on the arrival rate of new technologies. All else equal, an increase in $\bar{a}$ increases the time spent in learning new technologies, rather than in production. A higher quality of education β, or a higher quantity of education, T, reduce this learning cost. Finally, the inclusion of x implies that high skill workers are better able to adapt to new technologies. Galor and Moav (2000) allow for an increase in the rate of technological progress to generate an endogenous substitution toward more high skill workers. Although this would be a straightforward extension, the purposes of this illustration do not require mobility between skill groups.

2.2.4 Implications for Income Inequality

Substituting equations (2.2.5) and (2.2.6) into (2.2.2) yields the competitive wage per efficiency unit of labor as:

$$\begin{aligned} w_h &= \bar{w} g_h^{\rho} \left[n_h \left(1 - \tfrac{\bar{a}}{\beta T(1+x)}\right)\right]^{\rho-1} \\ w_l &= \bar{w} g_l^{\rho} \left[n_l \left(1 - \tfrac{\bar{a}}{\beta T}\right)\right]^{\rho-1}, \end{aligned} \tag{2.2.7}$$

where $\bar{w} = A\left[(g_h N_h)^{\rho} + (g_l N_l)^{\rho}\right]^{1/\rho - 1}$.

Income is the wage multiplied by the efficiency units of labor supply. For instance, a given high skill worker earns the wage w_h as given by equation (2.2.7) multiplied by their individual supply to production. The supply of labor for a high skill worker is the aggregate efficiency units of skilled labor, N_h, divided by the number of skilled workers, n_h, or $\frac{N_h}{n_h} = \left(1 - \frac{\bar{a}}{\beta T(1+x)}\right)$. Likewise, a low skill worker earns w_l multiplied by their production supply, $\frac{N_l}{n_l} = \left(1 - \frac{\bar{a}}{\beta T}\right)$. The incomes for high and low skill workers are,

$$\begin{aligned} I_h &= w_h \tfrac{N_h}{n_h} = \bar{w} g_h^{\rho}\left[n_h\left(1 - \tfrac{\bar{a}}{\beta T(1+x)}\right)\right]^{\rho-1}\left(1 - \tfrac{\bar{a}}{\beta T(1+x)}\right) \\ I_l &= w_l \tfrac{N_l}{n_l} = \bar{w} g_l^{\rho}\left[n_l\left(1 - \tfrac{\bar{a}}{\beta T}\right)\right]^{\rho-1}\left(1 - \tfrac{\bar{a}}{\beta T}\right). \end{aligned} \tag{2.2.8}$$

Inequality, Ω, is given by the relative income of a high skill worker, or I_h/I_l:

$$\Omega \equiv \frac{I_h}{I_l} = (1+\bar{a})^{\rho}\left(\frac{n_h}{n_l}\right)^{\rho-1}\left(\frac{\beta T(1+x) - \bar{a}}{(\beta T - \bar{a})(1+x)}\right)^{\rho}. \tag{2.2.9}$$

Equation (2.2.9) shows inequality to be shaped by three different forces. The first two are straightforward. The first term in parentheses reflects the skill biased nature of technological change. In this case, faster arrival rates of new technologies increase the relative demand for skilled workers who are better able to learn and adapt to the new technologies. The second term is the number of high skill workers relative to low skill workers. All else equal, an increase in the relative number of skilled workers will decrease income inequality.

The final term in equation (2.2.9) reflects how the interaction between the arrival rate of new technologies and educational factors play a role in the effective efficiency of high and low skill workers. An increase in the arrival rate of new technologies, $\bar{a}$, (all else equal) decreases the efficiency units of both types of labor. Moreover, this effect is relatively more substantial for low skill individuals. As a result, an increase in the arrival rate of new technologies not only increases inequality by raising the relative demand for high skill workers, but also increases the efficiency of high skill labor relative low skill labor. To illustrate, consider that

$$\frac{\partial\left(\frac{\beta T(1+x)-\bar{a}}{(\beta T-\bar{a})(1+x)}\right)^{\rho}}{\partial\bar{a}}=\rho\left(\frac{\beta T\left(1+x\right)-\bar{a}}{\left(\beta T-\bar{a}\right)\left(1+x\right)}\right)^{\rho-1}\left(\frac{x\beta T}{\left(1+x\right)\left(\beta T-\bar{a}\right)^{2}}\right)>0. \tag{2.2.10}$$

The third term in parentheses also includes both the quality of education and the difference in the schooling of high skill workers relative to low skill workers. The marginal impact of increases in educational quality and quantity, respectively, are given by

$$\frac{\partial\left(\frac{\beta T(1+x)-\bar{a}}{(\beta T-\bar{a})(1+x)}\right)^{\rho}}{\partial\beta}=-\rho\left(\frac{\beta T\left(1+x\right)-\bar{a}}{\left(\beta T-\bar{a}\right)\left(1+x\right)}\right)^{\rho-1}\left(\frac{\bar{a}xT}{\left(1+x\right)\left(\beta T-\bar{a}\right)^{2}}\right)<0, \tag{2.2.11}$$

and

$$\frac{\partial\left(\frac{\beta T(1+x)-\bar{a}}{(\beta T-\bar{a})(1+x)}\right)^{\rho}}{\partial T}=-\rho\left(\frac{\beta T\left(1+x\right)-\bar{a}}{\left(\beta T-\bar{a}\right)\left(1+x\right)}\right)^{\rho-1}\left(\frac{\bar{a}x\beta}{\left(1+x\right)\left(\beta T-\bar{a}\right)^{2}}\right)<0. \tag{2.2.12}$$

When the quality or quantity of education is high, all workers are better able to quickly learn new technologies, which narrows the efficiency gap.

Furthermore, this model also shows the role of education during periods of faster diffusion of new technologies, or when $\bar{a}$ is increased. Consider two countries that differ only in their educational characteristics. An increase in the arrival rate of new technologies increases inequality *more* in the country with a lower quality or quantity of education. Stated another way, a better quality or quantity of education reduce the impact of the arrival rate of new technologies on income inequality. The cross derivatives can be calculated to show this effect:

$$\frac{\partial\left[\left(\frac{\beta T(1+x)-\bar{a}}{(\beta T-\bar{a})(1+x)}\right)^{\rho}\right]^{2}}{\partial\bar{a}\partial\beta}<0 \text{ and } \frac{\partial\left[\left(\frac{\beta T(1+x)-\bar{a}}{(\beta T-\bar{a})(1+x)}\right)^{\rho}\right]^{2}}{\partial\bar{a}\partial T}<0 \tag{2.2.13}$$

Finally, the cross derivative of the third term with respect to the quality and quantity of education is positive. This implies, for example, that improving the quality of education reduces inequality more when the quantity of education is low. The quality of education is then of particular importance for developing countries with a lower overall quantity of education. It can be shown that:

$$\frac{\partial \left[\left(\frac{\beta T(1+x)-\bar{a}}{(\beta T-\bar{a})(1+x)} \right)^{\rho} \right]^2}{\partial \beta \partial T} > 0 \tag{2.2.14}$$

In sum, an increase in the arrival rate of new technologies unambiguously increases income inequality. However, if a country has a higher quality of education, β, or quantity of education, T, the change in inequality will be less.

2.2.5 Empirical Specification

The log of (2.2.9) is

$$\log[\Omega] = \rho \log[1+\bar{a}] - (1-\rho)\log\left[\frac{n_h}{n_l}\right] + \rho \log\left[\frac{\beta T(1+x)-\bar{a}}{(\beta T-\bar{a})(1+x)}\right] \tag{2.2.15}$$

and the first difference over time of (2.2.15) leads to an expression that describes the evolution of income inequality modified to incorporate the role technological change plays in the effective efficiency of labor supply:

$$\Delta\log[\Omega] = \rho\Delta\log[1+\bar{a}] - (1-\rho)\Delta\log\left[\frac{n_h}{n_l}\right] + \rho\Delta\log\left[\frac{\beta T(1+x)-\bar{a}}{(\beta T-\bar{a})(1+x)}\right]. \tag{2.2.16}$$

The empirical analysis uses data from a broad spectrum of countries to test the fundamental predictions contained in (2.2.16). Specifically, the log change in income inequality is a function of 1) the log change in the arrival rate of new technologies; 2) the log change in relative stock of high skill workers; 3) the quality of education; 4) the relative advantage in schooling or training of high skill workers; and 5) the interactions among the log change in the arrival rate of new technologies and the quality and quantity of education. The critical expected results are based on the marginal effects shown in (2.2.10), (2.2.13) and (2.2.14).

Consider the following reduced form empirical representation of (2.2.16)[8]:

[8]See appendix for an alternative specification.

$$\begin{aligned}\Delta\log\left[\Omega\right]_{t,0} &= \alpha+\beta_1\Delta\log\left[\bar{a}\right]+\beta_2\Delta\log\left[\frac{n_h}{n_l}\right]_{t,0} \\ &+\beta_3\log\left[QL\right]+\beta_4\log\left[T\right]+\beta_5\log\left[QL\right]\Delta\log\left[\bar{a}\right] \\ &+\beta_6\log\left[T\right]\Delta\log\left[\bar{a}\right]+\beta_7\log\left[QL\right]\log\left[T\right]+X'\beta_X+\epsilon,\end{aligned} \tag{2.2.17}$$

where $\Delta\log\left[\Omega\right]_{t,0}$ is the log change in inequality between the initial year 0 and year t, $\Delta\log\left[\bar{a}\right]$ is the log change in the arrival rate of new technologies, $\Delta\log\left[\frac{n_h}{n_l}\right]_{t,0}$ is the log change in the relative number of workers considered "skilled," $\log\left[QL\right]$ is the log of the quality of education, and $\log\left[T\right]$ is the log of the average years of education. Finally, X' captures other exogenous variables and ϵ is the error term. Clearly there is potential endogeneity between the dynamics of inequality and the change in the arrival rate of new technologies, and this issue is addressed specifically in the next section.

This empirical analysis captures the total effect of changes in the arrival rate of technologies on the dynamics of income inequality. The expectations on the coefficients linked to $\Delta\log\left[\bar{a}\right]$ are $\beta_1 > 0$, $\beta_5 < 0$ and $\beta_6 < 0$. Or, the total effect of changes in the arrival rate of new technologies on the growth of inequality is a function of the educational factors: $(\beta_1+\beta_5\log\left[QL\right]+\beta_6\log\left[T\right])$. The growth of inequality following an increase in technological diffusion differs across countries based, largely, on educational characteristics.

2.3 Data Measurement

2.3.1 Inequality

The measurement for income inequality is the Theil index (UTIP-UNIDO, 2002) which includes a large set developed and developing countries over an extended time frame. The Theil index is advantageous because it measures industrial wage inequality in the manufacturing sector, with data taken from the Industrial Statistics database published annually by the United Nations Development Organization. Another commonly used measure of inequality is the Gini coefficient (Deininger and Squire, 1996; 1998). However, this measures the concentration of income based on household surveys (See Deininger and Squire, 1996). Conceicao and Galbraith (2000) and others also find this measure to be incomplete in terms of country coverage over time and largely inconsistent with other measures of inequality. The Theil index (UTIP-UNIDO, 2002) provides a more complete measure of inequality over countries and over time and is closer in line with the analysis above. Atkinson (1997) shows that earnings and wage inequality are the main components of the larger distribution of income.

Figure 1.1 illustrates the median of the log change of the Theil index for five country cohorts: advanced countries, Middle Eastern and North African countries, Latin American countries, Sub-Saharan African countries and Asian countries. The data spans from 1960 until 1995 and is broken up into six ten-year periods.

The dynamics of inequality clearly changed after 1980 for each of the groups of countries. The median growth of inequality was negative or zero for each of the five groups of countries between 1965 and 1975, as well as from 1970 to 1980. However, the growth of inequality accelerated substantially during the 1980s. The median log change of inequality for each of the five groups was positive from 1980-1990, and furthermore, the log change from 1980-1990 was greater than the change from 1970-1980 and 1975-1985. In addition, for all except the advanced countries, the median change in inequality was less from 1985-1995 than from 1980-1990. This suggests the pace of the global growth of inequality has slowed since peaking from 1980-1990. The relative magnitude of the growth of inequality in the 1980s is also important. Inequality grew substantially more in Latin America and Africa relative to the other three cohorts, while the growth of inequality was lowest in the Asian countries for the periods 1980-1990 and 1985-1995.

2.3.2 Educational Factors

Measuring the quality of education is inherently difficult. Standard measures for the quality of education, including adult literacy rates, teacher-pupil ratios, teacher salaries or expenditures per student, are typically insignificant in cross-country growth studies, and are notoriously poor measures for the quality of education in the labor force. In addition, measures of the quantity of formal schooling, typically taken from the Barro-Lee datasets, do not fully capture the cognitive ability of the labor force since there is a lack of adjustment for the quality of the education. One year of education in the U.S. is not equivalent to one year of schooling in most developing countries. Hanushek and Kimko (2000) address this issue by developing measures for the quality of the labor force derived from a number of international mathematics and science tests between the years 1965 through 1991.[9] While test score data is available for only 39 countries, Hanushek and Kimko use consistent estimators to forecast labor force quality for a large number of countries based on country specific characteristics.[10] Table A.1 in the appendix details this quality of education measurement for countries according to their region (Hanushek and Kimko, 2000).

Using the Hanushek and Kimko measure, the poorest quality of the labor force education is 18.26 (Iran), while the highest is 72.13 (Singapore). The mean for the entire sample of 88 countries is 45.32 with a standard deviation of 13.15. Advanced countries had the highest average for the quality of education (56.04), followed by Asia (49.57), Latin America (40.22), Sub-Saharan Africa (39.20), and the Middle East/North Africa (32.70). Overall, the data supports the idea that the quality of education varies significantly and systematically across countries and regions.

Data for the proportion of the labor force considered to be high skilled is taken from the Barro-Lee dataset for persons aged 15 years and higher (Barro and Lee, 2000). The fraction $\frac{n_h}{n_l}$ is the stock of skilled workers relative to unskilled workers. If L is the total labor

[9] International math and science tests were conducted by the International Association for the Evaluation of Educational Achievement and the International Assessment of Educational Progress.

[10] Hanushek and Kimko produce two quality measures for countries across the development spectrum. The first measure converts the test scores to a mean of 50. This, however, assumes that the world performance in math and science in constant over time. The second measure (the measure used in this paper) relaxes this assumption, and allows for the global mean to drift based on the performance of U.S. students over time.

force divided into two skill cohorts, then the fraction can be rewritten as $\frac{n_h}{L-n_h}$. Dividing through by L yields $\frac{n_h}{n_l} = \frac{n_h/L}{1-n_h/L}$. The term n_h/L is then measured as the fraction of higher school attained in the total work force.[11] The empirical analysis also incorporates the initial quantity of education, again, from the Barro-Lee dataset. The average years of education allows for a direct comparison of the relative importance between the quality and the quantity of education in driving the dynamics of income inequality. Barro and Lee (2000) show very little direct correlation between the average years of education and the quality of education.

2.3.3 Arrival Rate of New Technologies

The final variable of interest is the change in the arrival rate of new technologies. It is important to note that the change in the arrival rate of new technologies is different than changes in the rate of technological progress or changes in overall economic growth. Greenwood and Yorukoglu (1997) document historically that an increase in the arrival rate of new technologies (ie. new communication and information technologies) leads to a temporary slowdown of productivity or economic growth. One of the main contributions of this paper is capturing the extent of the diffusion of new technologies through trade.

Quantifying the pace of technological diffusion is problematic. One widely cited source of technological diffusion is the development and usage of personal computers and the internet, dating back to the introduction of IBM-PC in 1981. Krueger (1993) uses the fraction of workers who use a computer on the job as a measure for the pace of technological change. Jorgenson (2001) uses the relative size of the information technology sector in the overall economy. Card and DiNardo (2002) offer a critical assessment of these measures of technological progress. For example, they cite evidence that the growth of inequality in the U.S. slowed during the 1990s despite continued improvement and usage of computer technologies. R&D expenditures and computer purchases are other measures to capture technological change utilized by Berman, Bound, and Griliches (1994). Berman, Bound,

[11]The fraction of those with at least some secondary education is also used to approximate the percentage of skilled workers in the labor force.

and Machin (1998), on the other hand, find the spread of microprocessor technologies to have led to both skill upgrading and rising inequality, especially in industries most dependent on computer technologies. Moreover, they find this trend to be pervasive throughout the developed world. However, their analysis is confined only to the twelve richest countries in 1985 due to industry specific data restrictions.

This paper takes a different approach to quantifying the change in the arrival rate of new technologies, which significantly increases the number of countries included. The arrival rate of new technologies accelerated during the 1980s, largely associated with new, general purpose communication and information technologies.[12] Also during this time, the majority of countries engaged in widespread trade liberalization, which helped facilitate the international diffusion of new technologies (Keller, 2004). This paper estimates the high technological (high skilled) factor content of imports to capture the change in the arrival rate of new technologies using a gravity model of industry-level bilateral trade. Opening up to trade with high skilled exporters implies that trade liberalization leads to a more pronounced change in the arrival rate of new technologies entering through trade. Using a gravity model with importer and exporter fixed effects, the skilled factor content of trade is estimated for 103 countries across the development spectrum. The gravity equation relates the factor content of imports to bilateral geographical distance, other bilateral trade impediments and multilateral resistance.

Advantageously, estimating the effects of factors embodied within imports controls for potential endogeneity between changes in income inequality and changes in the arrival rate of new technologies. Technological progress, inequality and trade flows are each endogenously determined processes. So while technological progress may explain the dynamics of inequality, the change in inequality may have an impact on the rate of technological progress. By estimating the high skill factor content of trade based on geographic proximity to high skilled exporters provides an exogenous proxy for changes in the arrival rate of new technologies. Therefore, the change in income inequality would have no impact on the skilled

[12] Greenwood and Yorukoglu (1997) show a faster pace of technological advancement linked to IT development beginning in the 1970s and through the 1980s. Also see Aghion (2002).

factor content of trade.

Estimating the high skill factor content of trade based on exogenous geographical factors and fixed effects also controls for the endogeneity of trade flows. Trade patterns are endogenously determined in a general equilibrium model. Endowments of human capital, education and technology matter when aggregate trade flows are determined. For example, Romalis (2004) finds that countries capture larger shares of world production and trade in commodities that more intensively use their abundant factor. Moreover, Romalis establishes the predictions of HOV theory hold qualitatively in the context of Krugman's model of monopolstic competition and transport costs. Coe and Helpman (1995), for example, use import shares as weights for international R&D spillovers. Empirical regressions based on import shares, however, potentially suffer from multicollinearity if two or more of the regressors are highly correlated.

Frankel and Romer (1999) utilize a gravity model to approximate general trade openness. Their paper isolates the geographical component of bilateral trade to show a causal relation between trade and growth. Auer (2006) follows an empirical strategy similar to Frankel and Romer to estimate the skilled factor content of trade. The gravity equations in Frankel and Romer (1999) and Auer (2006), however, are log-linearized, and use ordinary least squares techniques to relate the bilateral trade variable to bilateral distance, the size of each trading partner, and, in the case of Auer (2006), the endowment of skills of the exporter. This procedure is problematic for three important reasons, as detailed by Anderson and van Wincoop (2003, 2004) and others. First, Santos Silva and Tenreyro (2006) show that log-linearized gravity models estimated by OLS provide biased parameters in the presence of heteroskedasticity. Second, by log-linearizing the model, information is lost due to zero values of the dependent variable. When using industry level, bilateral trade data, it is not uncommon for there to be many observations with zero values. Often, small or remote countries did not trade in each industry in a certain period. These first two issues are addressed by estimating the model in its multiplicative form using pseudo-maximum-likelihood regression techniques. The third issue is that the gravity equations in Frankel and Romer (1999) and Auer (2006) do not take into account multilateral resistance terms. Anderson and van Wincoop (2003) provide a theoretical foundation for the gravity model which motivates the need to include the average trade barriers, or "multilateral resistance" terms. To account for multilateral resistance I utilize importer and exporter fixed effects. The fixed effects for exporters, for example, capture not only the endowment of skills in the exporter country, but also any other country specific, unobservable characteristic that impacts a country's propensity to export high skill goods.

This paper uses 1992 bilateral trade flow data from Feenstra et al. (2005), which documents industry level bilateral trade data for the years 1962-2000.[13] The productivity adjusted unit requirement matrix for each industry is from Antweiler and Trefler (2002). Specifically, the data contains information on the skilled labor input requirement for each industry based on U.S. production techniques. Using the vector of input requirements, bilateral trade flows are converted into the net factor content of trade. The data covers 37 tradable industries for the year 1992.[14] The actual skilled factor content of bilateral trade, for importer i and exporter o in industry j, is given by

$$sk\bar{F}CT_{j,i,o} = A^{sk}_{j,US} M_{j,i,o}, \tag{2.3.1}$$

where $sk\bar{F}CT$ denotes actual factor content of imports, $A^{sk}_{j,US}$ is the productivity adjusted skilled factor requirement as given by Antweiler and Trefler (2002), and $M_{j,i,o}$ is the imports from o to i in industry j. Summing across industries yields the total actual skilled factor content of trade between countries i and o, or

$$sk\bar{F}CT_{i,o} = \sum_{j} sk\bar{F}CT_{j,i,o}. \tag{2.3.2}$$

[13] Available from www.nber.org/data (International Trade Data, NBER-UN world trade data)

[14] Included industries: livestock, crops, forestry, fishing, coal, oil and gas, metal ore mining, other mining, food products, beverages, tobacco, textiles, wearing apparel (except footware), leather products, footwear (except rubber or plastic), wood products (except furniture), furniture (except metal), paper and products, printing and publishing, industrial chemicals, other chemicals, petroleum refineries, misc. petroleum and coal products, rubber products, plastic products, pottery, glass and products, other non-metallic mineral productions, iron and steel, non-ferrous metals, fabricated metal products, machinery (except electrical), machinery electric, transport equipment, profession and scientific equipment, other manufactured products, and electricity.

The result is a balanced data set consisting of 103 countries, or $(103)^2$ observations. The actual skilled factor content of trade is related to bilateral distance and other bilateral variables common in the literature, as well as importer and exporter fixed effects for the year 1992. Following Santos Silva and Tenreyro (2006), this paper uses a Poisson Psuedo-Maximum Likelihood (PPML) approach to estimate:

$$\begin{aligned} sk\bar{F}CT_{i,o} = \quad & \alpha + \gamma_i + \gamma_o + \beta_1 \log\left(DIST_{i,o}\right) + \beta_2 CONTIG_{i,o} \\ & + \beta_3 COMLANG_{i,o} + \beta_4 COLONY_{i,o} + \epsilon, \end{aligned} \tag{2.3.3}$$

where γ_i and γ_o are the importer and exporter fixed effects, $CONTIG$ is a dummy variable equal to 1 if the countries are contiguous, $COMLANG$ is a dummy variable equal to 1 if the countries share a common language, and $COLONY$ is a dummy variable equal to 1 if the countries share a common colonizer. $DIST_{i,o}$ is the population weighted distance between importer, i, and exporter, o. The distance variable was constructed as population weighted distances between city k in country i and city l in country o. Specifically, $DIST_{i,o} = \sum_{k \in i} \frac{pop_k}{pop_i} \sum_{l \in o} \frac{pop_l}{pop_o} dist_{k,l}$, where the distance between two cities, $dist_{k,l}$, is calculated by the Great Circle Distance Formula measured in kilometers and 32.186 kilometers is used as inner-city distance.[15] The results of the gravity model are presented in Table 2.1.

As expected, the distance between two countries is significant at the one percent level and negatively related to aggregate trade flows, and therefore the embodied skilled factor content of trade. Likewise, the dummy variables for common border and common language are significant at the one percent level and are of the expected sign. The dummy variable for sharing a common colonizer is insignificant in this specific gravity model of the high skill factor content of trade. Finally, the fixed effects capture any country specific factor related to the skilled factor content of imports or exports.

The predicted skilled factor content of imports for country i is attained by summing the

[15] All data on latitude, longitude, and population is from the World Gazetteer web page.

Gravity Model

Dependent Variable: Skilled Factor Content, 1992	
DIST	-0.22947
	(-2.90)***
CONTIG	1.37666
	(8.08)***
COMLANG	0.41918
	(3.43)***
COLONY	0.02739
	(0.22)
Obs.	10609

Table 2.1: t statistics are in parentheses; *** denotes significance at 1 percent level, ** 5 percent, * 10 percent. The dependent variable is the actual bilateral skilled factor content of imports in 1992, as described in the text. PPML estimation is used with robust standard errors and the t-statistic is listed in the parentheses. Importer and exporter fixed effects (not listed above) are included in the regression. The distance variable is constructed as described in the text. The balanced data set contains 103 countries (number of observations is 103^2).

predicted bilateral factor content of imports over all exporters for a given importer i, and then dividing by the country's population size. The values for the skilled factor content of imports are listed in Table 2.2.[16]

Skilled Factor Content of Trade

Latin America		**Asia**		**Africa**	
Argentina	0.0072409	Afghanistan	0.0003653	Benin	0.0012796
Bolivia	0.0025916	Bangladesh	0.0003596	Burkina Faso	0.0004021
Brazil	0.0019248	China	0.0007677	Cameroon	0.0012236
Chile	0.0107447	India	0.0003041	Cent. Afr. Rep.	0.0004295
Colombia	0.0028176	Indonesia	0.0022542	Chad	0.0002637
Costa Rica	0.0121631	Korea	0.026701	Congo	0.0002225
Dom. Rep.	0.0075502	Malaysia	0.0341533	Ethiopia	0.0002427
Ecuador	0.0037287	Myanmar	0.0003632	Gabon	0.0116976
El Salvador	0.0035435	Nepal	0.0003199	Ghana	0.0010364
Guatemala	0.0032297	Pakistan	0.001021	Guinea	0.0010161
Haiti	0.0004397	Papua N. G.	0.0037095	Kenya	0.0008151
Honduras	0.0039117	Philippines	0.0026756	Liberia	0.0407032
Jamaica	0.0124387	Singapore	0.3675235	Madagascar	0.0004126
Mexico	0.0118086	Sri Lanka	0.002081	Malawi	0.000736
Nicaragua	0.0015917	Taiwan	0.0506817	Mali	0.0004937
Panama	0.0691125	Thailand	0.0106587	Mauritania	0.0027648
Paraguay	0.0058322			Mozambique	0.0007582
Peru	0.0021504			Niger	0.000336
Suriname	0.0141919			Nigeria	0.0012159
Uruguay	0.0089918			Rwanda	0.0002771

(Continued on Next Page...)

[16]The predicted high skill factor content of imports for each country in the sample (103) is significantly greater than zero at the one percent level. Standard errors were determined by bootstrapping the gravity model to generate 50 unique values. Results are available upon request.

Skilled Factor Content of Trade (Continued...)

Venezuela	0.0104886			Senegal	0.0016575
				Sierra Leone	0.0003352
				Somalia	0.000081
				South Africa	0.0072606
				Sudan	0.0003527
				Tanzania	0.0005785
				Togo	0.0020322
				Uganda	0.0002087
				Yemen	0.00185
				Zambia	0.0015859
				Zimbabwe	0.0019223
Mean	0.0093568		0.0314962		0.0027158
Std. Dev.	0.0143338		0.0908462		0.0074208
Obs.	21		16		31
Mid. East		**Advanced**			
Algeria	0.0043277	Australia	0.0373746		
Egypt	0.0027159	Austria	0.1099863		
Iran	0.005022	Belgium	0.1724751		
Iraq	0.000074	Bulgaria	0.003862		
Israel	0.0561946	Canada	0.070257		
Jordan	0.0092179	Denmark	0.0955809		
Morocco	0.0039257	Finland	0.059059		
Saudi Arabia	0.030682	France	0.062738		
Syria	0.0030593	Germany	0.0737405		
Tunisia	0.0120111	Greece	0.0320445		

(Continued on Next Page...)

Skilled Factor Content of Trade (Continued...)

UAE	0.1079606	Hungary	0.0131613	
		Ireland	0.0961746	
		Italy	0.0430329	
		Japan	0.0223234	
		Netherlands	0.1335309	
		New Zealand	0.0420976	
		Norway	0.0991316	
		Poland	0.0049923	
		Portugal	0.0464989	
		Spain	0.0374452	
		Sweden	0.0888332	
		Turkey	0.0052734	
		U.K.	0.0573415	
		USA	0.0336995	
Mean	0.021381		0.0600272	
Std. Dev.	0.0332136		0.0426681	
Obs.	11		24	

Table 2.2: List of the constructed high skill factor content of imports per capita. Each index is calculated as the sum of the predicted factor content of imports from each country source divided by the population of the importer, as described in the text. The predicted high skill factor content of imports for each country in the sample (103) is significantly greater than zero at the one percent level. Standard errors were determined by bootstrapping the PPML gravity model to generate 50 unique values. Results are available upon request. Values are in thousands of 1992 U.S. dollars.

The values in Table 2.2 are interpreted as the high skill factor content of imports divided by the population (measured in thousands of 1992 U.S. dollars). For example, the value for Mexico is 0.0118, which means the average skilled factor content of imports per person

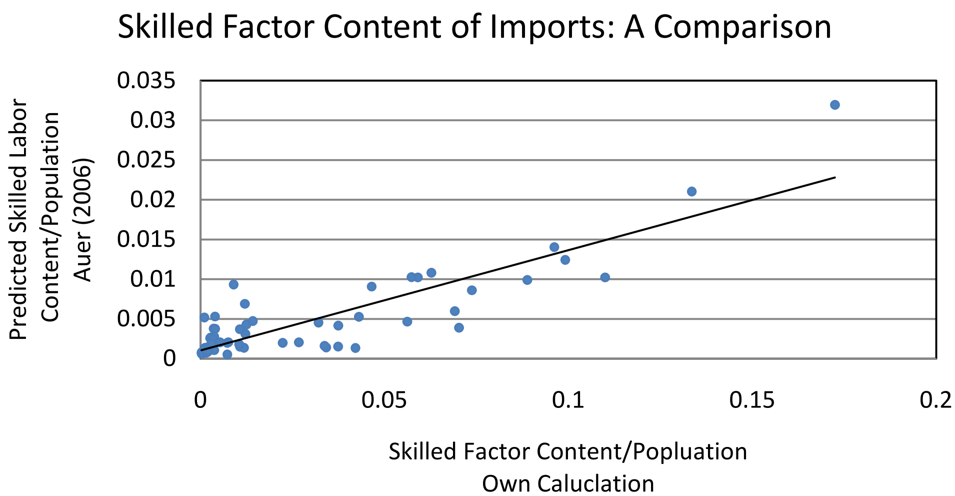

Figure 2.1: The values on the x-axis are the skilled factor content of imports divided by the population as calculated in this paper. The values on the y-axis correspond to the predicted skilled labor content divided by the population in Auer (2006). A total of 62 countries have measures for the factor content of imports in both sets of data.

in Mexico is 0.0118. Higher values correspond to a higher skilled factor content of trade, and a larger increase in the arrival rate of new technologies following trade liberalization. The median skilled factor content of imports per person is the highest in advanced countries (0.05192), followed by Latin America (0.005832), the Middle East (0.005022), Asia (0.002168), and Africa (0.000758) has the lowest skilled factor content of trade.

Figure 2.1 compares the calculation for the skilled factor content of trade from this paper to that of Auer (2006). As expected there is a positive relationship between the two measures for the factor content of trade, however the calculations from this paper are larger in magnitude. The reason is that Auer (2006) only considers the average years of education of the exporter to capture the high skill content of exports. By using multilateral resistance terms, the measure from this paper captures all factors specific to each exporter that contributes to a larger skilled factor content of exports.

2.3.4 Summary of Data

The vector of other explanatory variables, X', includes GDP per capita, a dummy variable for advanced countries, regional dummy variables (Asia, Latin America, Africa and Middle East/North Africa) and overall trade openness. The inclusion of the GDP per capita (data from the Penn World Tables 6.2, Heston et al., 2006) controls for other factors that depend on the level of development. The dummy variable for advanced countries captures systematic differences in the dynamics of inequality between developed and developing countries. Regional dummy variables capture other systematic differences across developing countries. A measure for corruption from *Transparency International* is included as a robustness check. Finally, I include the Frankel and Romer (1999) measure for "natural openness", based on domestic population size and proximity to large markets. This allows for the consideration of the effects of the technology embodied within trade while holding constant a measure of the extent of trade.

Table 2.3 summarizes the data central to the empirical analysis, broken up into regions: Africa, Latin America, Asia, the Middle East, and advanced countries, which includes the U.S., Canada, Australia, New Zealand, Japan, and most of Europe. The table describes the log change in the Theil index from 1980-90 and 1980-95, the quality of education, the skilled factor content of trade (skFCT) and the log change in the fraction of the population with skills between 1980 and 1990.

Table 2.3 provides some interesting insights. Inequality grew between 1980 and 1990 in each group of countries, despite significant overall skill upgrading during the this time period (the log change in the fraction of the labor force with higher education was positive in each region). The growth of inequality was most substantial in Latin America. This region is characterized by a high skill factor content of trade and a low average quality of education. Asia, on the other hand, had a low skill factor content of trade and a high quality of education, which contributed to a very low growth of inequality (the median log change of inequality was actually negative between 1980 and 1995). The advanced countries, similar to Asia, had a high quality of education, but also the highest skill factor content. Inequality

Summary Statistics

		$\Delta \log Theil$ 1980-90	$\Delta \log Theil$ 1980-95	Quality of Education	skFCT	$\Delta \log \frac{sk}{Pop}$ 1980-90
Africa	Obs.	17	10	15	31	25
	Median	0.551	0.372	38.90	0.0007582	0.423
	Mean	0.451	0.198	39.20	0.0027158	0.559
	Std. Dev.	0.495	0.627	9.43	0.0074208	0.617
	Min.	-0.563	-0.814	25.58	0.0000809	-0.624
	Max.	1.116	0.990	54.95	0.0407032	1.705
Latin America	Obs.	18	15	21	21	23
	Median	0.634	0.728	39.34	0.0058322	0.478
	Mean	0.599	0.566	40.22	0.0093568	0.486
	Std. Dev.	0.550	0.585	9.60	0.0143338	0.202
	Min.	-1.027	-1.233	24.74	0.0004397	0.015
	Max.	1.484	1.178	59.80	0.0691125	0.942
Asia	Obs.	13	11	13	16	18
	Median	0.154	-0.039	54.29	0.0021676	0.515
	Mean	0.142	0.012	49.57	0.0314962	0.467
	Std. Dev.	0.528	0.549	16.74	0.0908462	0.388
	Min.	-0.460	-0.582	20.80	0.0003041	-0.288
	Max.	1.188	1.238	72.13	0.3675235	1.099
Middle East/ North Afr.	Obs.	11	9	11	11	11
	Median	0.266	0.229	28.06	0.0050220	0.546
	Mean	0.435	0.494	32.70	0.0213810	0.551
	Std. Dev.	0.570	0.633	11.43	0.0332136	0.301
	Min.	-0.297	-0.158	18.26	0.0000740	0.057
	Max.	1.419	1.671	54.46	0.1079606	0.916
Advanced Countries	Obs.	23	22	27	24	25
	Median	0.193	0.531	56.61	0.0519202	0.271
	Mean	0.219	0.665	55.47	0.0600273	0.350
	Std. Dev.	0.583	0.748	7.15	0.0426681	0.290
	Min.	-1.742	-1.076	39.72	0.0038620	-0.122
	Max.	1.598	2.199	67.06	0.1724751	1.099
Full Sample	Obs.	82	67	88	103	103
	Median	0.309	0.476	46.35	0.0038620	0.422
	Mean	0.367	0.443	45.32	0.0238880	0.473
	Std. Dev.	0.560	0.677	13.15	0.0478080	0.398
	Min.	-1.742	-1.233	18.26	0.0000740	-0.624
	Max.	1.598	2.199	72.13	0.3675235	1.705

Table 2.3: Summary Statistics

grew more in advanced economies between 1980 and 1995 than each of the other regions except for Latin America. A cursory look at the data suggests the growth of inequality was most severe in countries with a high skill factor content of imports and a low quality of education.

2.4 Estimation Results

The empirical analysis considers the role of the quality of education, the quantity of education, the changes in the arrival rate of new technologies and changes in the endowment of skills in explaining the dynamics of income inequality. I proceed, first, with cross sectional regressions using the log change of inequality from both 1980-1990 and 1980-1995 as dependent variables. I, then, subdivide the data into three time intervals (1980-1985, 1985-1990, and 1990-1995) and estimate panel regressions. I show robust evidence that a higher skill factor content of trade increases the growth of inequality, while both the quality and the quantity of education directly reduce the changes of inequality. In addition, the interaction terms are equally important. A higher quality of education reduces the impact of new technologies on the growth of inequality whereas the interaction of the quantity of education and skill factor content of trade is insignificant. The impact of changes in the arrival rate of new technologies depends on the quality of education, rather than its quantity. The interaction between the quality and quantity of education is also important. Specifically, the role of the quality of education in driving the dynamics of education is stronger when the average years of education is low. Thus, the quality of education is even more important for developing countries whose average years of education is relatively less than in advanced economies. Finally, the qualitative results carry through for each of the time intervals, however the absolute magnitude and significance of the results increase over the longer time frame, 1980-1995.

2.4.1 Empirical Results: 1980 - 1990

Table 2.4 presents the results for equation (2.2.17), which regresses the log change in inequality between 1980 and 1990 against the skill factor content of trade, the quality and quantity of education, the change in the relative stock of skilled workers over the same time period, and the three interactions among the skilled factor content of trade and the educational variables (all in logs).

The ordinary least squares regressions of equation (2.2.17) are split into six columns. The first column contains only the key variables of interest, while column (2) adds a measure of overall trade openness. Column (3) includes trade openness and the initial real GDP per capita. Column (4) includes a dummy variable for advanced economies and the measure for overall trade openness. Column (5) contains trade openness and regional dummy variables for the Middle East/North Africa, Africa, Latin America, and Asia, and column (6) uses a combination of overall trade openness, initial GDP per capita and regional dummy variables.[17]

In columns (1) - (4) the skilled factor content of imports is significant and positive at the one percent level. Even after controlling for regional differences, as in columns (5) and (6), the coefficient remains positive and significant. A larger change in the arrival rate of new technologies increases the growth of income inequality, however, the strength of this effect depends on the quality of education. The interaction between the skill factor content of imports and the quality of education is negative and significant at the one percent level. A higher quality of education reduces the impact of new technologies on the growth of inequality. The interaction with the quantity of education (measured using the average years of education) with the skilled factor content is insignificantly different from zero.[18] Overall, it is the quality of education, rather than the quality of education, that reduces the

[17] Each regression also included the Corruption Perceptions Index provided by Transparency International. Two measures were included. The first is the average corruption index for 1980-1985. This measure is not available for a large number of countries, so the overall average corruption measure is also used to expand the number of countries with available data. For each specification, corruption increased the growth of inequality but this effect was not significantly different from zero. These results are not included in this section, but are available upon request.

[18] When this interaction is dropped from the regression analysis, there is little change to the significance and magnitude of the other variables. See the appendix for results.

Regression Results #1
Dependent Variable: $\Delta \log Theil$, 1980 - 1990

Column	1	2	3	4	5	6
$skFCT$	1.365	1.385	1.205	1.329	0.749	0.829
	(3.350)***	(3.490)***	(3.480)***	(3.210)***	(1.780)*	(1.730)*
QL	-4.014	-4.092	-3.639	-3.800	-2.939	-3.205
	(-3.770)***	(-3.790)***	(-3.450)***	(-3.630)***	(-1.940)*	(-1.790)*
$skFCT * QL$	-0.391	-0.399	-0.343	-0.372	-0.221	-0.245
	(-4.390)***	(-4.630)***	(-4.130)***	(-3.880)***	(-1.770)*	(-1.680)*
$YEARS$	-5.509	-5.514	-5.420	-5.219	-5.748	-6.016
	(-2.290)**	(-2.350)**	(-2.290)**	(-2.300)**	(-2.180)**	(-2.180)**
$skFCT * YEARS$	0.032	0.030	-0.056	-0.005	-0.006	-0.020
	(0.290)	(0.270)	(-0.510)	(-0.040)	(-0.050)	(-0.160)
$QL * YEARS$	1.447	1.459	1.295	1.325	1.431	1.478
	(2.510)**	(2.540)**	(2.220)**	(2.430)**	(2.030)**	(2.030)**
$\Delta \frac{n_h}{n_l}$	-0.234	-0.225	-0.225	-0.211	-0.131	-0.153
	(-1.350)	(-1.280)	(-1.270)	(-1.190)	(-0.810)	(-0.880)
Openness		0.047	0.102	0.056	0.032	0.065
		(0.430)	(0.880)	(0.500)	(0.290)	(0.410)
GDPp.c. (1980)			0.327			0.118
			(1.900)*			(0.430)
Advanced				0.155		
				(1.010)		
Mideast					-0.190	-0.209
					(-0.680)	(-0.680)
Africa					-0.304	-0.240
					(-1.360)	(-0.960)
Latin America					0.155	0.165
					(0.630)	(0.660)
Asia					-0.430	-0.340
					(-2.180)**	(-1.090)
Constant	15.398	15.444	11.146	14.568	11.589	11.472
	(3.460)***	(3.570)***	(2.580)**	(3.440)***	(2.210)**	(2.250)**
N	59	59	59	59	59	59
R squared	0.191	0.195	0.246	0.204	0.320	0.323

Table 2.4: t-statistics are in parentheses; *** denotes significance at 1 percent, ** 5 percent, * 10 percent. OLS estimation is used for each regression with robust standard errors. The dependent variable is the log change of the Theil index between 1980 and 1990.

impact of new technologies on the change in inequality.

The elasticity of inequality growth with respect to the skilled factor content of trade on the change in inequality is a function of the educational variables. For example, in column (4) the elasticity for the proxy of new technologies is $(1.329 - 0.372 \log QL + 0.03 \log YEARS)$. As the quality of education increases, the effect of new technologies on the growth of inequality falls. For example, for Bolivia, whose quality of education is 27.47, this elasticity implies that a ten percent increase in the skilled factor content of trade increases the growth of inequality by 1.42 percent. For Mexico, whose quality of education is 37.24, a ten percent increase in the factor content of trade increases the growth of inequality by only 0.3 percent. A ten point increase in the quality of education significantly reduces the growth of inequality results from the diffusion of new technologies through trade.

While the quality of education is the only significant education variable interacted with the skilled factor content of imports, both the quality and quantity of education significantly reduce the growth of income inequality. In fact, the direct coefficients on the average years of education are larger in magnitude than the direct coefficients on the quality of education, especially once controlling for regional differences. However, the total effect of each of the educational variables depends on one another and the skilled factor content of imports. Again focusing on column (4) from Table 2.4, the elasticity of the quality of education is $(-3.8 - 0.372 \log skFCT + 1.325 \log YEARS)$. A higher $skFCT$ implies the quality of education becomes more important in reducing the growth of inequality. A higher average years of education, $YEARS$, however, reduces the impact of the quality of education on the dynamics of inequality. This suggests the quality of education is more important to the dynamics of inequality for developing countries with relatively low average years of education.

The change in the stock of skilled workers relative to unskilled workers is, as expected, negatively related to the change in inequality. An increase in the relative number of skilled workers reduces income inequality, however the coefficient is not quite significant at the ten percent level. Finally, it is interesting that the initial level of development (log of the real

GDP per capita in 1980) is positive and significant at the ten percent level. This implies the growth of inequality was greater for developed countries. However, the inverted U-shape relationship between inequality and income, as proposed in the Kuznets hypothesis, implies the growth of inequality should be declining with income. When including regional dummy variables, the story becomes more clear. The growth of inequality in Asian countries is significantly less than the growth of inequality in advanced economies, even after controlling for the impact of new technologies and other educational factors. Finally, the Frankel-Romer measure of overall trade openness is not significant in the cross country regressions. This result implies that it is the high technological component of trade that impacts the growth of inequality, rather than trade itself.

2.4.2 Empirical Results: 1980 - 1995

The regressions are duplicated over a slightly extended time interval, 1980 to 1995. The results echo those in the previous subsection, however the absolute magnitude of the variables increases by a factor between 2 and 3. Overall, this supports the idea that the new technologies and the quality of education are important, long lasting determinants of the dynamics of income inequality. Table 2.5 presents the results for equation (2.2.17) for the change in inequality between 1980 and 1995.

The coefficients are consistent across each of the six columns in Table 2.5, although much larger in absolute magnitude than the regression coefficients from 1980 - 1990. Beginning with the skilled factor content of trade, the implied total elasticity in column (6) is given by $(3.014 - 0.678 \log QL - 0.325 \log YEARS)$. Again, a higher quality of education reduces the impact of a faster arrival rate of new technologies on the dynamics of inequality. Moreover, the relative magnitude is roughly equal to those of the shorter time interval.

The quantity of education does not significantly reduce the impact of new technologies. The direct impact of the quality and quantity of education is, as expected, negative and significant and the interaction between the two variables is positive. This suggests that the quality of education is a relatively more important determinant for the dynamics of

Regression Results #2
Dependent Variable: $\Delta \log Theil$, 1980 - 1995

Column	1	2	3	4	5	6
$skFCT$	3.213	3.225	2.727	2.967	2.814	3.014
	(5.310)***	(5.450)***	(4.460)***	(4.790)***	(3.180)***	(3.540)***
QL	-10.106	-10.112	-9.356	-9.016	-8.901	-9.854
	(-5.220)***	(-5.150)***	(-4.940)***	(-4.530)***	(-3.240)***	(-3.670)***
$skFCT * QL$	-0.764	-0.763	-0.660	-0.691	-0.612	-0.678
	(-5.050)***	(-5.010)***	(-4.400)***	(-4.110)***	(-2.660)**	(-2.940)***
$YEARS$	-15.385	-15.480	-14.903	-13.668	-14.692	-15.798
	(-3.490)***	(-3.450)***	(-3.510)***	(-3.250)***	(-3.030)***	(-3.410)***
$skFCT * YEARS$	-0.169	-0.173	-0.219	-0.217	-0.296	-0.325
	(-0.780)	(-0.790)	(-1.040)	(-1.040)	(-1.270)	(-1.450)
$QL * YEARS$	3.869	3.881	3.643	3.326	3.508	3.747
	(3.830)***	(3.780)***	(3.700)***	(3.440)***	(3.090)***	(3.470)***
$\Delta \frac{n_h}{n_l}$	-0.111	-0.117	-0.127	-0.101	-0.105	-0.151
	(-0.610	(-0.650	(-0.770	(-0.600	(-0.650	(-0.850
Openness		-0.024	0.076	0.022	0.012	0.097
		(-0.200)	(0.560)	(0.190)	(0.090)	(0.630)
GDPp.c. (1980)			0.448			0.334
			(1.760)*			(0.890)
Advanced				0.468		
				(2.410)**		
Mideast					-0.476	-0.500
					(-1.710)*	(-1.750)*
Africa					-0.218	-0.075
					(-0.620)	(-0.240)
Latin America					-0.348	-0.329
					(-1.210)	(-1.110)
Asia					-0.591	-0.335
					(-2.340)**	(-0.980)
Constant	40.257	40.463	33.149	36.268	36.913	37.275
	(4.930)***	(4.890)***	(3.660)***	(4.390)***	(3.340)***	(3.550)***
N	52	52	52	52	52	52
R squared	0.355	0.355	0.396	0.413	0.431	0.443

Table 2.5: t-statistics are in parentheses; *** denotes significance at 1 percent, ** 5 percent, * 10 percent. OLS estimation is used for each regression with robust standard errors. The dependent variable is the log change of the Theil index between 1980 and 1995.

inequality in countries with (1) a higher skill factor content of trade, and (2) lower average years of education.

The real GDP per capita in 1980 and the dummy for advanced economies, columns (3) and (4), are positive and significant at the ten and five percent levels respectively. This suggests a systematic higher growth of inequality in developed countries compared to developing countries. Including regional dummies for developing countries, columns (5) and (6), reveal it is the Middle East/North Africa and Asia that has a systematically lower growth of inequality, with each dummy being significant at the five percent level. General trade openness remains insignificant.

2.4.3 Empirical Results with Pooled Data

This section pools the data across three intervals to, again, show the importance of the interaction between changes in the rate of technological progress and educational variables in accounting for the growth of income inequality. Specifically, the data is divided into three periods: 1980-85, 1985-90, and 1990-95, where the dependent variable is the log change of inequality during the specified time period. Dummy variables are included for each of the sets of years, where "Time: 1985-90" is equal to one if the dependent variable is the log change of inequality between 1985 and 1990, and "Time: 1990-95" is equal to one if the dependent variables is the log change of inequality between 1990 and 1995. Table 2.6 present the results.

The results obtained from the pooled regression, shown in Table 2.6, confirm the cross-sectional results from above. A higher skilled factor content of imports, along with lower qualities and quantities of education increase the growth of inequality. Moreover, the quality of education significantly reduces the impact of new technologies on the growth of inequality, whereas the interaction between the skilled factor content of imports and the quantity of education is consistently insignificant. Overall trade openness, the log change in the relative stock of high skill workers, along with the time dummy variables, are insignificant, while the growth of inequality in Asia is significantly less than the growth in advanced economies.

Regression Results #3
Dependent Variable: $\Delta \log Theil$, 1980-1985, 1985-1990, 1990-1995

Column	1	2	3	4	5	6
$skFCT$	0.672	0.687	0.647	0.660	0.483	0.476
	(3.04)***	(3.11)***	(2.90)***	(2.93)***	(1.99)**	(1.87)*
QL	-2.337	-2.387	-2.314	-2.184	-1.890	-1.868
	(-3.56)***	(-3.58)***	(-3.46)***	(-3.27)***	(-2.66)***	(-2.32)**
$skFCT * QL$	-0.200	-0.206	-0.198	-0.193	-0.149	-0.147
	(-4.41)***	(-4.38)***	(-3.99)***	(-3.85)***	(-2.67)***	(-2.35)**
$YEARS$	-3.247	-3.245	-3.271	-2.983	-3.062	-3.046
	(-2.42)**	(-2.44)**	(-2.46)**	(-2.28)**	(-2.22)**	(-2.12)**
$skFCT * YEARS$	0.028	0.030	0.130	0.008	0.012	0.012
	(0.47)	(0.51)	(0.23)	(0.14)	(0.18)	(0.19)
$QL * YEARS$	0.913	0.920	0.894	0.810	0.825	0.822
	(3.01)***	(3.05)***	(2.96)***	(2.74)***	(2.62)***	(2.53)**
$\Delta \frac{n_h}{n_l}$	-0.185	-0.174	-0.189	-0.168	-0.074	-0.069
	(-0.61)	(-0.58)	(-0.66)	(-0.56)	(-0.25)	(-0.22)
Openness		0.023	0.037	0.029	0.021	-0.018
		(0.41)	(0.70)	(0.54)	(0.43)	(0.35)
GDPp.c. (1980)			0.102			-0.012
			(1.23)			(-0.08)
Advanced				0.144		
				(2.19)**		
Mideast					-0.145	-0.144
					(-0.94)	(-0.90)
Africa					-0.204	-0.209
					(-1.59)	(-1.40)
Latin America					-0.051	-0.053
					(-0.56)	(-0.55)
Asia					-0.228	-0.237
					(-2.93)***	(-1.60)
Time: 1985-90	0.087	0.086	0.086	0.087	0.087	0.087
	(1.18)	(1.18)	(1.18)	(1.19)	(1.18)	(1.17)
Time: 1990-95	0.099	0.100	0.101	0.102	0.101	0.101
	(1.38)	(1.39)	(1.40)	(1.43)	(1.39)	(1.36)
Constant	8.420	8.471	7.316	7.852	6.884	6.922
	(3.00)***	(3.03)***	(2.53)**	(2.82)***	(2.33)**	(2.37)**
N	172	172	172	172	172	172
R squared	0.112	0.113	0.121	0.126	0.142	0.142

Table 2.6: t-statistics are in parentheses; *** denotes significance at 1 percent, ** 5 percent, * 10 percent. OLS estimation is used for each regression with robust standard errors. The dependent variable is the log change of the Theil index for three time intervals: 1980-85, 1985-90, and 1990-95.

2.5 Conclusions

This paper emphasizes the importance of the quality of education in the determination of the dynamics of inequality, most notably during times of rapid technological progress. Not only did countries with a higher quality of education experience less growth in inequality, but the impact of technological progress was lessened as well. Consider the rapid growth of inequality during the 1980s. This decade was marked by the rapid development of new information and communication technologies, and also widespread trade liberalization facilitating the diffusion of new technologies throughout developing countries. This paper shows a robust positive relationship between the high skill factor content of trade and the growth of income inequality. Moreover, a higher quality of education lessens the magnitude of this relationship. This is an important contribution to explaining the low growth of inequality in Asia with a high quality of education, and the rapid growth of inequality in Latin America and Africa.

To illustrate the importance of the quality of education, consider the case of Brazil, an emerging economy that significantly reduced trade barriers during the 1980s and 1990s. Specifically, the average tariff rate fell from 41.2 percent to 17.8 percent from the late 1980s to the early 1990s, while the value of imports more than tripled between 1988 and 1995, growing from $14,605 to $49,859 millions of US dollars (Source: Central Bank of Brazil). The quality of the labor force given by the Hanushek and Kimko (2000) measure for Brazil is 36.60 and, using the empirical estimates provided in column (4) from Table 2.5, the projected growth of income inequality between 1980 and 1995 is 41.22 percent. However, had the quality of the labor force been equal to that in Indonesia (42.99), the projected growth of inequality would be reduced to 26.36 percent. Furthermore, using the quality of the labor force of Thailand (46.26), the expected growth of inequality falls to only 19.59 percent. Improving the quality of education not only directly reduces the growth of inequality, but also lessens the impact of new technologies embodied within trade.

The finding that the quality of education lessens the growth of inequality provides empirical support for the Nelson-Phelps view of skill biased technological change. This theory, extended by Galor and Moav (2000) and Aghion (2002) among others, emphasizes the comparative advantage of skilled workers at adapting to faster rates of technological change. If the quality of education is high, the labor force as a whole is better equipped to learn the new technologies, thus reducing the comparative advantaged held by skilled workers. Furthermore, the results suggest careful attention should be placed on the effects of technological change on the effective human capital. Faster rates of technological change have implications not only for the relative demand for skills, but also the relative efficiency of the different skill cohorts. The intuitive results support the Nelson-Phelps view of the relationship between technological change and income inequality.

This is the principle policy implication as well. Investment in the quality of education is vital during periods of rapid technological progress. The effects of globalization and the spread of new technologies on income inequality is especially important to emerging economies. Without strong investment into improving the quality of education, a rapid increase in the arrival rate of new technologies is shown to contribute to rapid growth of income inequality.

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Appendix A. Quality of Education

Table 1 summarizes the quality of education measure from Hanushek and Kimko (2000). The measures for the quality of the labor force are derived from a number of international mathematics and science tests between the years 1965 through 1991. While test score data is available for only 39 countries, Hanushek and Kimko use consistent estimators to forecast labor force quality for a large number of countries based on country specific characteristics. The International math and science tests were conducted by the International Association for the Evaluation of Educational Achievement and the International Assessment of Educational Progress. Hanushek and Kimko produce two quality measures for countries across the development spectrum. The first measure converts the test scores to a mean of 50. This, however, assumes that the world performance in math and science in constant over time. The second measure (detailed in Table 1) relaxes this assumption, and allows for the global mean to drift based on the performance of U.S. students over time.

Labor-Force Quality Data

Advanced		**Latin America**		**Asia**		**Africa**		**Mid. East**	
Australia	59.04	Bolivia	27.47	China	64.42	Botswana	31.71	Algeria	28.06
Austria	56.61	Brazil	36.60	Hong Kong	71.85	Cameroon	42.36	Bahrain	23.19
Belgium	57.08	Chile	24.74	Indonesia	42.99	Congo	50.90	Cyprus	46.24
Canada	54.58	Colombia	37.87	Korea	58.55	Ghana	25.58	Egypt	26.43
Denmark	61.76	Ecuador	38.99	Malaysia	54.29	Kenya	29.95	Iran	18.26
Finland	59.55	Honduras	28.59	Philippines	33.54	Lesotho	51.95	Iraq	27.50
France	56	Mexico	37.24	Singapore	72.13	Mauritius	54.95	Israel	54.46
Germany	48.68	Peru	41.18	Taiwan	56.32	Mozambique	27.94	Jordan	42.48
Greece	50.88	Uruguay	52.27	Thailand	46.26	Nigeria	38.90	Kuwait	22.50
Hungary	61.23	Venezuela	39.08	Fiji	58.10	S. Africa	51.30	Syria	30.23
Iceland	51.2	Argentina	48.50	Papua N.G.	22.58	Swaziland	40.26	Tunisia	40.50
Ireland	50.2	Barbados	59.80	Sri Lanka	42.57	Togo	32.60		
Italy	49.41	Costa Rica	46.15	India	20.80	Zaire	33.53		
Japan	65.5	Dom. Rep.	39.34			Zambia	36.61		
Netherlands	54.52	El Salvador	26.21			Zimbabwe	39.64		
New Zealand	67.06	Guyana	51.49						
Norway	64.56	Jamaica	48.62						
Poland	64.37	Nicaragua	27.30						
Portugal	44.22	Panama	46.78						
Spain	51.92	Paraguay	39.96						
Sweden	57.43	Trin. & Tob.	46.43						
Switzerland	61.37								
Turkey	37.72								
U.K.	62.52								
U.S.A.	46.77								
Luxembourg	44.49								
Malta	57.14								
Median	56.61		40.22		49.57		39.20		32.70
Std. Dev.	7.15		9.60		16.74		9.43		11.43
Obs.	27		21		13		15		11

Table A.1: Data is the $QL2$ measure from Hanushek and Kimko (2000).

Appendix B. Detailed Equations

Northern and Southern Average Profits

This appendix provides more details for equations (1.3.17) and (1.3.18). Firms located in the North whose closest competitor is a Northern firm obtain a flow sum of domestic and export profits,

$$\pi_{NN} = \overbrace{(q-1)\,H_N\Lambda_N Q_N}^{\text{Domestic Profits}} + \overbrace{(q-1)\,(1+\tau_{XS})\left(\frac{\tilde{P}}{1+\tau_{XS}}\right)^{\frac{1}{1-\alpha}} H_S\Lambda_S Q_N}^{\text{Export Profits}}. \tag{B.0.1}$$

where $\Lambda_N = A_N^{1/(1-\alpha)}\left(\frac{\alpha}{q}\right)^{1/(1-\alpha)}$, and $Q_N = \int_0^1 q^{k_{N_j}\alpha/(1-\alpha)}dj$ is the average quality level on the frontier. Northern firms facing Southern competition, likewise, earn a sum of import and export profits

$$\begin{aligned}\pi_{NS} = {} & \overbrace{\left(q\tilde{P}\,(1+\tau_{XN})-1\right)\left(\frac{1}{\tilde{P}\,(1+\tau_{XN})}\right)^{\frac{1}{1-\alpha}} H_N\Lambda_N Q_N}^{\text{Domestic Profits}} + \\ & \underbrace{\left(q\tilde{P}-(1+\tau_{XS})\right) H_S\Lambda_S Q_N}_{\text{Export Profits}}\end{aligned} \tag{B.0.2}$$

where the size of the incremental quality increase, q, must be sufficiently large such the limit price exceeds the marginal cost of production. Average profits for intermediate firms in the North is

$$\begin{aligned}\pi_N &= \tfrac{n_{NN}\pi_{NN}+n_{NS}\pi_{NS}}{n_{NN}+n_{NS}} \\ &\equiv \bar{\pi}_N Q_N\end{aligned} \tag{B.0.3}$$

where $\bar{\pi}_N$ is the profits adjusted for the average quality level on the frontier. Trade barriers and the probability of innovation are embedded within $\bar{\pi}_N$. A change in the rate of innovation and imitation, alter the effective levels of human capital (H_N and H_S), the equilibrium relative price of the Southern final good ($\tilde{P}_S = MC_S$), and the distribution of firms (n_{NN}, n_{NS}, and n_S).

The partial effects of trade liberalization on the Northern average profits is given by,

$$\frac{\partial \bar{\pi}_N}{\partial \tau_{XS}} = -\frac{H_S \Lambda_S}{n_{NN} + n_{NS}} \left(n_{NN} (q-1) \left(\frac{\alpha}{1-\alpha} \right) \left(\frac{\tilde{P}_S}{1+\tau_{XS}} \right)^{1/(1-\alpha)} + n_{NS} \right) < 0$$

$$\frac{\partial \bar{\pi}_N}{\partial \tau_{XN}} = -H_N \Lambda_N \left(\tilde{P}_S (1+\tau_{XN}) \right)^{1/(\alpha-1)} \frac{1 - \alpha q \tilde{P}_S (1+\tau_{XN})}{(1-\alpha)(1+\tau_{XN})} < 0$$

Southern flow profits for intermediate producers are

$$\begin{aligned} \pi_S &= \overbrace{\left(1+\tau_{XS}-\tilde{P}\right)\left(\frac{q\tilde{P}}{1+\tau_{XS}}\right)^{\frac{1}{1-\alpha}} H_S \Lambda_S Q_N}^{\text{Domestic Profits}} + \overbrace{\left(1-\tilde{P}(1+\tau_{XN})\right) q^{\frac{1}{1-\alpha}} H_N \Lambda_N Q_N}^{\text{Export Profits}} \\ &\equiv \bar{\pi}_S Q_N \end{aligned} \tag{B.0.4}$$

where $\Lambda_S = A_S^{1/(1-\alpha)} \left(\frac{\alpha}{q}\right)^{1/(1-\alpha)}$, and, as in the North, $\bar{\pi}_S$ is the quality adjusted profits for Southern imitators. I assume the Northern tariff is sufficiently low such that the export profits for Southern firms, given the limit price, is positive. Since only the state-of-the-art technology is used, any good produced in the South will still have the same quality level as the lead Northern quality frontier.

The partial effects of trade liberalization on the Northern average profits is given by,

$$\frac{\partial \bar{\pi}_S}{\partial \tau_{XS}} = \left(\frac{q\tilde{P}_S}{1+\tau_{XS}} \right)^{\frac{1}{1-\alpha}} H_S \Lambda_S Q_N \left[\frac{\tilde{P}_S - \alpha (1+\tau_{XS})}{(1-\alpha)(1+\tau_{XS})} \right] > 0$$

$$\frac{\partial \bar{\pi}_S}{\partial \tau_{XN}} = -q^{1/(1-\alpha)} H_N \Lambda_N Q_N \tilde{P}_S < 0$$

Resources Allocated to R&D

Using the two world resource constraints, the expressions for Z_N and Z_S from equations (1.4.4) and (1.4.5) are, in the North,

$$\begin{aligned} Z_N &= \Bigg[H_N \Lambda_N \left(\tfrac{q}{\alpha}\right) \left[n_{NN} + n_{NS} \left(\tfrac{1}{\tilde{P}_S (1+\tau_{XN})}\right)^{\frac{\alpha}{1-\alpha}} + n_S q^{\frac{\alpha}{1-\alpha}}\right] \\ &\quad - n_{NN} \left(H_N \Lambda_N + H_S \Lambda_S \left(\tfrac{\tilde{P}_S}{1+\tau_{XS}}\right)^{\frac{1}{1-\alpha}}\right) \\ &\quad - n_{NS} \left(H_S \Lambda_S + H_N \Lambda_N \left(\tfrac{1}{\tilde{P}_S (1+\tau_{XN})}\right)^{\frac{1}{1-\alpha}}\right) - \chi_N\Bigg] Q_N \\ &\equiv \bar{Z}_N \left(\tau_{XS}, \tau_{XN}, p_I\right) Q_N \end{aligned}$$

where

$$\frac{\bar{Z}_N}{\partial \tau_{XS}} = -\frac{n_{NN} H_S \Lambda_S}{(1-\alpha)(1+\tau_{XS})} \left(\frac{\tilde{P}_S}{1+\tau_{XS}}\right)^{1/(1-\alpha)} < 0$$

$$\frac{\bar{Z}_N}{\partial \tau_{XN}} = \frac{n_{NS} H_N \Lambda_N}{(1-\alpha)(1+\tau_{XN})} \left(\frac{1}{\tilde{P}_S (1+\tau_{XN})}\right)^{1/(1-\alpha)} \left[1 - \tilde{P}_S (1+\tau_{XN})\right] > 0$$

and in the South,

$$\begin{aligned} Z_S &= \Bigg[H_S \Lambda_S \left(\tfrac{q}{\alpha}\right) \left[n_{NN} \left(\tfrac{\tilde{P}_S}{1+\tau_{XS}}\right)^{\frac{\alpha}{1-\alpha}} + n_{NS} + n_S \left(\tfrac{q\tilde{P}_S}{1+\tau_{XS}}\right)^{\frac{\alpha}{1-\alpha}}\right] \\ &\quad - n_S q^{\frac{1}{1-\alpha}} \left(H_S \Lambda_S \left(\tfrac{\tilde{P}_S}{1+\tau_{XS}}\right)^{\frac{1}{1-\alpha}} + H_N \Lambda_N\right) - \chi_S\Bigg] Q_N \\ &\equiv \bar{Z}_S \left(\tau_{XS}, \tau_{XN}, p_I\right) Q_N \end{aligned}$$

where

$$\frac{\partial \bar{Z}_S}{\partial \tau_{XS}} = -\frac{q H_S \Lambda_S}{\tilde{P}_S (1-\alpha)} \left(\frac{\tilde{P}_S}{1+\tau_{XS}}\right)^{1/(1-\alpha)} \left[n_{NN} + n_S q^{\alpha/(1-\alpha)} \left(1 - \frac{\tilde{P}_S}{1+\tau_{XS}}\right)\right] < 0$$

where $\chi_N = C_N/Q_N$ and $\chi_S = C_S/Q_N$. $\bar{Z}_N$ and $\bar{Z}_S$ are the quality adjusted expenditures on R&D.

Balanced Trade Condition

The relative price of the Southern final good adjusts at each point of time to balance trade between the North and South. Expanding equation 1.4.6, $\tilde{P}_S$ implicitly solves,

$$qH_S\Lambda_S\left[n_{NS}\tilde{P}_S + n_{NN}\left(1+\tau_{XS}\right)\left(\frac{\tilde{P}_S}{1+\tau_{XS}}\right)^{1/(1-\alpha)}\right] - n_S H_N \Lambda_N q^{1/(1-\alpha)} = 0$$

where the partial effects of trade liberalization is given by,

$$\frac{\partial \tilde{P}_S}{\partial \tau_{XS}} = \frac{n_{NN}\left(\frac{\alpha}{1-\alpha}\right)\left(\frac{\tilde{P}_S}{1+\tau_{XS}}\right)^{\frac{1}{1-\alpha}}}{n_{NS} + \frac{1}{1-\alpha}n_{NN}\left(\frac{\tilde{P}_S}{1+\tau_{XS}}\right)^{\frac{\alpha}{1-\alpha}}} > 0$$

Appendix C. Southern Trade Liberalization - All Variables

Panels 1 thru 20 show the evolution of the other key variables. The variables Y_m, X_m, Z_m and C_m are presented adjusting for aggregate quality. Each, however, grows at a rate equal to the growth rate of technologies on the frontier, $\dot{Q}_N/Q_N$. Additionally, each variable is presented as the percentage change from the initial steady state. Figure C.1 refers to the case in which the quality of education in the South is low, and Figure C.2 refers to the case in which the quality of education in the South is high.

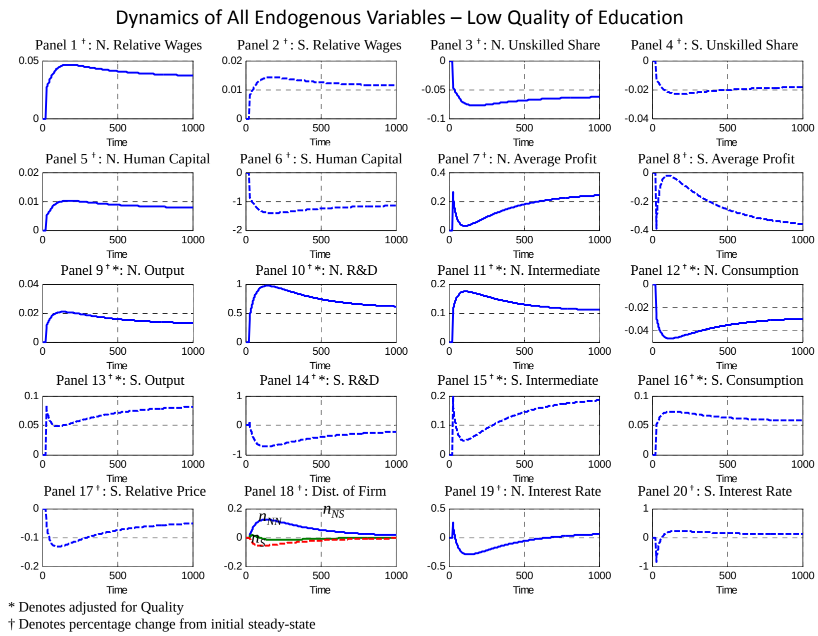


Figure C.1: Denotes the transitional dynamics of all endogenous variables following Southern trade liberalization when the South has a low quality of education. Given as the percentage change from the initial steady state.

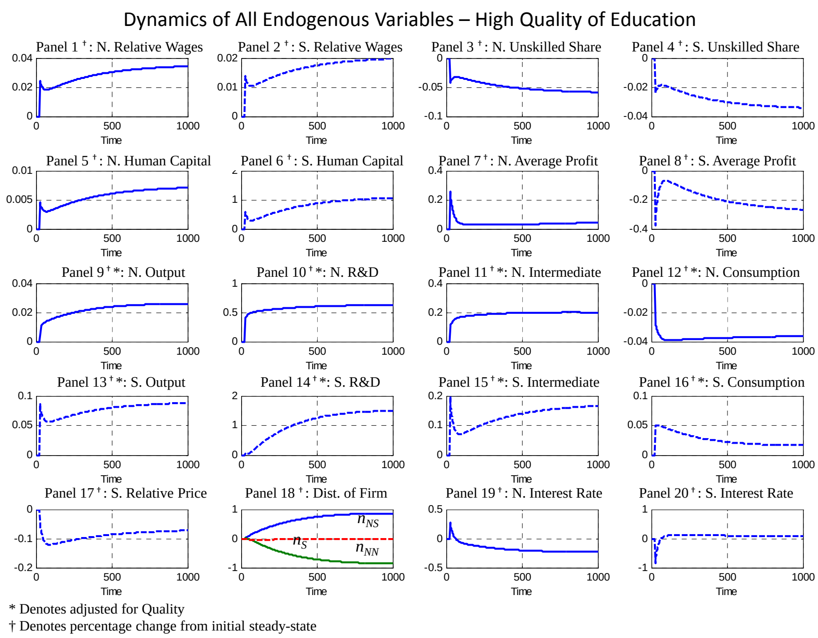


Figure C.2: Denotes the transitional dynamics of all endogenous variables following Southern trade liberalization when the South has a high quality of education. Given as the percentage change from the initial steady state.

Appendix D. Alternative Empirical Specification

As an alternative to the empirical representation given by equation (2.2.17) consider

$$\begin{aligned}\log[\Omega]_t &= \alpha + \beta_0 \log[\Omega]_0 + \beta_1 \Delta \log[\bar{a}] + \beta_2 \Delta \log\left[\tfrac{n_h}{n_l}\right]_{t,0} \\ &+\beta_3 \log[QL] + \beta_4 \log[T] + \beta_5 \log[QL]\,\Delta\log[\bar{a}] \\ &+\beta_6 \log[T]\,\Delta\log[\bar{a}] + \beta_7 \log[QL]\log[T] + X'\beta_X + \epsilon,\end{aligned} \tag{D.0.1}$$

where $\log[\Omega]_t$ and $\log[\Omega]_0$ are the log of inequality in year t and 0 respectively, $\Delta\log[\bar{a}]$ is the log change in the arrival rate of new technologies captured by the high skill factor content of imports, $\Delta\log\left[\frac{n_h}{n_l}\right]_{t,0}$ is the log change in the relative number of workers considered "skilled," $\log[QL]$ is the log of the quality of education, and $\log[T]$ is the log of the average years of education. Finally, X' captures other exogenous variables and ϵ is the error term.

The difference between (2.2.17) and (D.0.1) is the manner in which the log change in inequality is specified. In (2.2.17), the dependent variable is the simple change in the log of inequality, or $\Delta\log[\Omega]_{t,0} = \log[\Omega]_t - \log[\Omega]_0$. In (D.0.1), the dependent variable is $\log[\Omega]_t$. However, the second empirical specification controls for the initial inequality, so the model is still testing the dynamics of inequality. Based on (D.0.1), $\Delta\log[\Omega]_{t,0} = \log[\Omega]_t - \beta_0\log[\Omega]_0$, whereas in equation (2.2.17), β_0 is restricted to unity.

Table D.1 presents the results based on equation (D.0.1), where the dependent variable is the log Theil in 1990, and the log Theil in 1980 is an explanatory variable. This specification captures the effects of new technologies and educational variables on the level of inequality after controlling for the initial level. Thus, this regression is still focusing on the dynamics of inequality.

The results in Table D.1 are, in general, less significant and lower in magnitude compared

Regression Results #4
Dependent Variable: $\log Theil$, 1990

Column	1	2	3	4	5	6
$Theil$ 1980	0.753	0.751	0.796	0.746	0.761	0.744
	(6.590)***	(6.590)***	(6.140)***	(6.340)***	(5.850)***	(5.000)***
$skFCT$	1.008	1.029	0.996	1.031	0.526	0.442
	(2.730)***	(2.820)***	(2.820)***	(2.810)***	(1.540)	(0.880)
QL	-1.871	-1.946	-2.087	-1.953	-1.397	-1.056
	(-1.530)	(-1.580)	(-1.650)	(-1.570)	(-0.910)	(-0.490)
$skFCT * QL$	-0.291	-0.299	-0.287	-0.302	-0.161	-0.136
	(-3.030)***	(-3.150)***	(-3.090)***	(-3.100)***	(-1.390)	(-0.820)
$YEARS$	-1.751	-1.735	-2.356	-1.708	-2.743	-2.291
	(-0.690)	(-0.680)	(-0.870)	(-0.670)	(-0.960)	(-0.670)
$skFCT * YEARS$	0.000	-0.003	-0.043	0.003	-0.014	-0.003
	(0.000)	(-0.030)	(-0.390)	(0.020)	(-0.120)	(-0.020)
$QL * YEARS$	0.376	0.383	0.487	0.384	0.614	0.513
	(0.590)	(0.590)	(0.730)	(0.590)	(0.780)	(0.560)
$\Delta\frac{n_h}{n_l}$	-0.239	-0.229	-0.228	-0.231	-0.174	-0.158
	(-1.420)	(-1.350)	(-1.330)	(-1.360)	(-1.100)	(-0.930)
Openness		0.053	0.081	0.051	0.033	0.006
		(0.570)	(0.770)	(0.540)	(0.330)	(0.040)
GDPp.c. (1980)			0.174			-0.100
			(0.900)			(-0.330)
Advanced				-0.027		
				(-0.190)		
Mideast					-0.037	-0.010
					(-0.130)	(-0.030)
Africa					-0.015	-0.047
					(-0.060)	(-0.180)
Latin America					0.318	0.321
					(1.600)	(1.640)
Asia					-0.243	-0.305
					(-1.300)	(-1.030)
Constant	6.852	6.856	6.097	6.830	4.961	4.562
	(1.370)	(1.390)	(1.280)	(1.380)	(0.920)	(0.770)
N	59	59	59	59	59	59
R squared	0.784	0.786	0.789	0.786	0.817	0.817

Table D.1: t-statistics are in parentheses; *** denotes significance at 1 percent, ** 5 percent, * 10 percent. OLS estimation is used for each regression with robust standard errors. The dependent variable is the log of the Theil index in 1990.

to the results in Table 2.4. For example, the average years of education does not significantly explain the level of inequality in 1990 after controlling for the initial level of inequality. The loss of significance is most likely due to endogeneity between the initial level of inequality in 1980 and the average years of education in 1980. Additionally, the direct impact of the quality of education is only significant at the fifteen percent level. The skilled factor content of trade is, however, significant at the one percent level and of the expected sign, particularly in columns (1) - (4). Its interaction with the quality of education is also negative and highly significant. Thus, the key result that the quality of education is important to reducing the impact of new technologies on inequality still holds for both specifications 2.2.17 and D.0.1. Finally, the inclusion of the regional dummy variables, columns (5) and (6), reduces the significance of each variable of interest.

Table D.2 documents the results for equation (D.0.1) using the log Theil in 1995 as the dependent variable controlling for the initial level of 1980 inequality.

The key results linking the arrival rate of new technologies and the quality of education to the dynamics of income inequality are again found in Table D.2. A higher skilled factor content of trade increases inequality, yet this effect is lessened by a higher quality of education. In contrast to Table D.2, the direct effect of the quality of education on the dynamics of inequality is negative and significant at the five percent level. The average years of education and its interactions are, once again, not significant for any of the specifications.

D.0.1 Results - Dropping Insignificant Interaction

Tables D.3 and D.4 test equation (2.2.17) for the time intervals 1980-1990 and 1980-1995 respectively without the interaction between $YEARS$ and $skFCT$.

Using the values from the column (3) regressions on Tables D.3 and D.4, Figure D.1 plots the actual log change of inequality against the predicted log change of inequality. The predictions of the model closely follow the actual change of inequality between 1980 and 1990, as well as 1980 and 1995.

Improving the quality of education for developing countries is especially important during

Regression Results #5
Dependent Variable: $\log Theil$, 1995

Column	1	2	3	4	5	6
$Theil$ 1980	0.493	0.488	0.518	0.531	0.513	0.507
	(3.460)***	(3.360)***	(3.350)***	(3.650)***	(3.340)***	(3.020)***
$skFCT$	1.996	1.969	1.826	1.970	1.605	1.565
	(3.000)***	(2.850)***	(2.510)**	(2.770)***	(1.750)**	(1.620)
QL	-5.078	-5.023	-4.991	-5.005	-4.215	-4.038
	(-2.390)**	(-2.290)**	(-2.280)**	(-2.230)**	(-1.550)	(-1.400)
$skFCT * QL$	-0.504	-0.503	-0.473	-0.496	-0.351	-0.339
	(-2.940)***	(-2.870)***	(-2.640)**	(-2.660)**	(-1.480)	(-1.300)
$YEARS$	-6.216	-5.997	-6.300	-6.057	-6.396	-6.156
	(-1.430)	(-1.310)	(-1.400)	(-1.340)	(-1.310)	(-1.220)
$skFCT * YEARS$	-0.096	-0.089	-0.114	-0.113	-0.219	-0.214
	(-0.500)	(-0.450)	(-0.580)	(-0.580)	(-1.020)	(-0.990)
$QL * YEARS$	1.472	1.433	1.473	1.413	1.391	1.336
	(1.420)	(1.330)	(1.400)	(1.310)	(1.190)	(1.110)
$\Delta \frac{n_h}{n_l}$	-0.125	-0.115	-0.120	-0.109	-0.106	-0.100
	(-0.750)	(-0.690)	(-0.740)	(-0.660)	(-0.670)	(-0.550)
Openness		0.034	0.074	0.048	0.016	0.005
		(0.360)	(0.730)	(0.510)	(0.150)	(0.040)
GDPp.c. (1980)			0.195			-0.042
			(0.710)			(-0.110)
Advanced				0.189		
				(1.010)		
Mideast					-0.072	-0.064
					(-0.280)	(-0.230)
Africa					0.135	0.121
					(0.390)	(0.370)
Latin America					-0.061	-0.060
					(-0.270)	(-0.260)
Asia					-0.365	-0.394
					(-1.600)	(-1.200)
Constant	18.872	18.380	16.485	18.529	16.435	16.141
	(2.100)**	(1.940)*	(1.640)	(1.950)*	(1.470)	(1.450)
N	52	52	52	52	52	52
R squared	0.652	0.652	0.658	0.659	0.677	0.677

Table D.2: t-statistics are in parentheses; *** denotes significance at 1 percent, ** 5 percent, * 10 percent. OLS estimation is used for each regression with robust standard errors. The dependent variable is the log of the Theil index in 1995.

Regression Results #6
Dependent Variable: $\Delta \log Theil$, 1980 - 1990

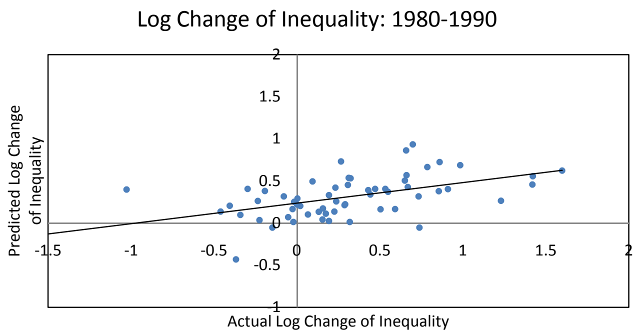
Column	1	2	3	4	5	6
$skFCT$	1.328	1.351	1.274	1.335	0.759	0.854
	(2.700)***	(2.800)***	(3.280)***	(2.790)***	(1.660)	(1.650)
QL	-3.977	-4.058	-3.725	-3.809	-2.959	-3.252
	(-3.530)***	(-3.570)***	(-3.390)***	(-3.360)***	(-2.000)*	(-1.820)*
$skFCT * QL$	-0.368	-0.377	-0.383	-0.376	-0.226	-0.260
	(-2.950)***	(-3.030)***	(-3.660)***	(-3.060)***	(-1.800)*	(-1.650)
$YEARS$	-5.845	-5.827	-4.902	-5.176	-5.705	-5.875
	(-3.090)***	(-3.120)***	(-2.480)**	(-2.840)***	(-2.180)**	(-2.190)**
$QL * YEARS$	1.498	1.506	1.226	1.320	1.427	1.464
	(2.920)***	(2.950)***	(2.260)**	(2.640)**	(2.030)**	(2.020)**
$\Delta \frac{n_h}{n_l}$	-0.222	-0.213	-0.245	-0.213	-0.133	-0.158
	(-1.320)	(-1.270)	(-1.410)	(-1.250)	(-0.800)	(-0.890)
Openness		0.048	0.097	0.055	0.032	0.064
		(0.440)	(0.890)	(0.520)	(0.290)	(0.410)
GDPp.c. (1980)			0.305			0.113
			(2.040)**			(0.430)
Advanced				0.152		
				(1.080)		
Mideast					-0.190	-0.208
					(-0.690)	(-0.690)
Africa					-0.305	-0.245
					(-1.370)	(-0.990)
Latin America					0.157	0.172
					(0.700)	(0.740)
Asia					-0.426	-0.333
					(-2.460)**	(-1.090)
Constant	15.484	15.526	11.296	14.568	11.616	11.557
	(3.590)***	(3.710)***	(2.660)***	(3.480)***	(2.230)**	(2.290)**
N	59	59	59	59	59	59
R squared	0.191	0.194	0.244	0.204	0.320	0.323

Table D.3: t-statistics are in parentheses; *** denotes significance at 1 percent, ** 5 percent, * 10 percent. OLS estimation is used for each regression with robust standard errors. The dependent variable is the log change of the Theil index between 1980 and 1990.

Regression Results #7
Dependent Variable: $\Delta \log Theil$, 1980 - 1995

Column	1	2	3	4	5	6
$skFCT$	3.174	3.179	2.717	2.926	2.559	2.699
	(4.990)***	(5.060)***	(4.070)***	(4.230)***	(2.890)***	(3.060)***
QL	-9.808	-9.807	-9.049	-8.708	-8.042	-8.738
	(-5.190)***	(-5.120)***	(-4.700)***	(-4.250)***	(-2.940)***	(-3.130)***
$skFCT * QL$	-0.828	-0.828	-0.751	-0.777	-0.685	-0.744
	(-4.970)***	(-4.960)***	(-4.410)***	(-4.270)***	(-2.960)***	(-3.120)***
$YEARS$	-13.232	-13.247	-12.187	-11.025	-10.920	-11.513
	(-4.230)***	(-4.180)***	(-3.850)***	(-3.530)***	(-2.880)***	(-3.110)***
$QL * YEARS$	3.502	3.503	3.197	2.894	2.858	2.999
	(4.190)***	(4.130)***	(3.720)***	(3.470)***	(2.820)***	(3.040)***
$\Delta \frac{n_h}{n_l}$	-0.136	-0.139	-0.154	-0.130	-0.099	-0.136
	-0.790	(-0.810	(-0.980	(-0.790	(-0.630	(-0.790
Openness		-0.010	0.085	0.037	0.043	0.114
		(-0.080)	(0.590)	(0.300)	(0.320)	(0.710)
GDPp.c. (1980)			0.405			0.267
			(1.650)			(0.740)
Advanced				0.439		
				(2.190)**		
Mideast					-0.485	-0.504
					(-1.600)	(-1.610)
Africa					-0.485	-0.391
					(-1.540)	(-1.250)
Latin America					-0.304	-0.286
					(-1.040)	(-0.960)
Asia					-0.572	-0.366
					(-2.190)**	(-1.020)
Constant	37.845	37.903	30.661	33.368	31.177	31.023
	(5.270)***	(5.230)***	(3.610)***	(4.280)***	(3.020)***	(3.050)***
N	52	52	52	52	52	52
R squared	0.344	0.344	0.378	0.395	0.407	0.415

Table D.4: t-statistics are in parentheses; *** denotes significance at 1 percent, ** 5 percent, * 10 percent. OLS estimation is used for each regression with robust standard errors. The dependent variable is the log change of the Theil index between 1980 and 1995.



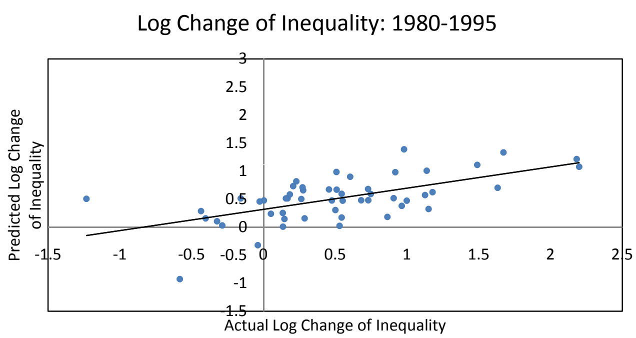


Figure D.1: The values on the x-axis are the actual log change of inequality for either 1980-1990 or 1980-1995. The values on the y-axis correspond to the predicted log change of inequality over the same time interval.

times of greater technological progress. The 1980s was a time of large scale trade liberalization which significantly changed the arrival rate of new technologies in developing countries. A higher quality of education in Asia compared to Latin America and Africa meant that the growth of inequality would be less severe. In fact, referring back to Figure 1.1, this is precisely what is found in the data. While a higher quantity of education does significantly reduce the growth of inequality, during times of rapid technological change, it is the quality of education has a greater impact. This result has an important policy implication. Improving the quality of education during periods of rapid technological progress is crucial for emerging and developing countries concerned with the effects of the new technologies on income inequality.

Consider the differences between Indonesia, whose quality of education is 42.99, and Brazil, whose quality of education is slightly less, 36.6. Using column (4) from Table D.4, a ten percent increase in the skilled factor content of trade increases the growth of inequality by 1.2 percent in Brazil, but only by 0.03 percent in Indonesia. Small differences in the quality of education have important implications for the growth of inequality associated with technological change. Furthermore, using column (4) of Table D.4, a ten percent increase in the quality of education reduces the growth of inequality, on average, by 18.7 percent in Africa (with a very low quantity of education), but only 4.6 percent in advanced countries.

Tables D.3 and D.4 also show systematic differences in the growth of inequality between developed and developing countries. For example, the log of the real GDP per capita in 1980 is positive and significant in Table D.3, while the dummy for advanced economies is positive and significant in Table D.4. The interaction between the factor content of trade and the quality of education remains a crucial factor in the dynamics of inequality, however there is evidence that there may be other factors that increase the growth of inequality in developed countries more than in developing countries. Moreover, the dummy for Asia is negative and significant in both Table D.3 and Table D.4. After controlling for the quality of education and the proxy for changes in the arrival rate of new technologies, the growth of inequality was less in Asia relative to the other regions. Tables D.3 and D.4, again, consistently show overall trade openness to be insignificant in the cross-country regressions.

Vita

Joshua Dennis Hall was born in Fort Wayne, Indiana, on June 16th, 1983. Below contains information regarding his current position, educational background, awards and honors, and his teaching and professional experience. His research interests include Macroeconomics, Economic Growth, Inequality, Education, and International Trade.

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   (a) Assistant Professor, University of Tampa, John H. Sykes College of Business, Department of Economics.
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   (a) Ph.D. in Economics (2010), Drexel University, Philadelphia, PA
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   (a) Drexel University Research Award, 2009
   (b) LeBow College of Business Outstanding Student Instructor Award, 2009.
   (c) Southern Economic Association Graduate Student Award, 2008
   (d) International Travel Award, Drexel University, 2008
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   (a) Instructor, ECON202 Principles of Macroeconomics (full responsibility): Spring 2008, Winter 2009, Spring 2009, Drexel University.
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   (b) The Diffusion of Technology, Education and Income Inequality: Evidence from Developed and Developing Countries. (2010).
   (c) Optimal R&D Policy in a Growth Model with Heterogeneous Firms. (with Christopher Laincz). (2010).